REPORT No. 507

TESTS OF NACELLE-PROPELLER COMBINATIONS IN VARIOUS POSITIONS WITH REFERENCE TO WINGS

VI—WINGS AND NACELLES WITH PUSHER PROPELLER

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SUMMARY

This report is the sixth of a series giving the results obtained in the N.A.C.A. 20-foot wind tunnel on the interference drag and propulsive efficiency of nacelle-propeller-wing combinations. The first three reports of the series gave the results of tests of radial-engine nacelles with tractor propellers and numerous types of engine cowling. Tests were made with the nacelles in various positions with respect to a thick monoplane wing and a Clark Y monoplane wing. The fourth report covered tests of tandem-propeller nacelles for radial engines with numerous types of cowling, in various positions with reference to a thick monoplane wing. The fifth report of the series gave the results of tests of an N.A.C.A. cowled nacelle with tractor propeller in various positions with reference to a biplane wing cellule of Clark Y section. The present report gives the results of tests of a radial-engine nacelle with pusher propeller in 17 positions with reference to a Clark Y wing; tests of the same nacelle and propeller in three positions with reference to a thick wing; and tests of a body and pusher propeller with the thick wing, simulating the case of a propeller driven by an extension shaft from an engine within the wing. Some preliminary tests were made on pusher nacelles alone.

The Clark Y wing had a 38-inch chord and a 15-foot 10-inch span. The thick wing had a 5-foot chord, a 15-foot span, and a thickness of 20 percent of the chord. The nacelle was built around a 4/9-scale model of a Wright J-5 radial air-cooled engine and was fitted with a cowling of the variable-angle ring type. The body simulating the extension-shaft case was formed by fairing into a thick wing the electric motor used for driving the propeller. The propeller was a 4-foot-diameter model of the Navy No. 4412 adjustable metal propeller.

Lift, drag, and propulsive efficiency were determined for each wing-nacelle combination at several angles of attack. Net efficiency was computed by the method developed in N.A.C.A. Technical Report No. 415 with a modification allowing for the effects of induced drag and tunnel boundary interference; a comparison was made, on this basis, between the pusher combinations tested and the tractor combinations of previous reports of this series.

The most favorable location for a pusher nacelle of the type tested, for high-speed flight, is with the thrust line about 60 percent of the wing chord below the center line of the wing, and with the propeller between 10 percent and 30 percent of the chord length behind the trailing edge. In the climbing condition one nacelle location has little advantage over another. The pusher nacelle tested was found, in its most favorable position, to be approximately as good as a tractor nacelle with a similar type of cowling in the most favorable tractor location, but inferior to tractor arrangements with the best cowling. The results obtained by simulating the case of a pusher propeller driven by an extension shaft from an engine enclosed in the wing, indicate that a propeller driven in this manner is much more efficient than any of the radial-engine nacelle and wing combinations of the series.

INTRODUCTION

This is the sixth of a series of reports on a general investigation of the mutual effects of wings, propellers, and engine nacelles. The investigation has included tractor, pusher, and tandem propellers, and both monoplane and biplane wings. Numerous types of radial-engine cowling have been tested, and several propeller pitch settings used.

The first three reports of the series (references 1, 2, and 3) dealt with tests of radial-engine nacelles with tractor propellers in conjunction with monoplane wings of thick section and of Clark Y section. Various types of engine cowling were tested with both wings. The fourth report (reference 4) gave results of tandem engine nacelles with numerous types of cowling tested in different positions with respect to a thick monoplane wing. The fifth report (reference 5) covered tests of an N.A.C.A. cowled tractor nacelle in various positions relative to a biplane wing cellule.

The present report presents the results of tests of a radial-engine nacelle with pusher propeller in 17 positions relative to a wing of Clark Y section, and in 3 representative positions relative to a thick wing. The nacelle and cowling used were selected after preliminary tests on pusher nacelles alone. Additional tests were made with the propeller mounted in two positions directly behind the thick wing, the model engine and nacelle being removed and the electric motor that drove the propeller faired into the wing. The resulting body was similar to the support for an extension shaft from an engine enclosed in the wing. The majority of the tests were made on the Clark Y wing as most pusher installations are on relatively thin, braced wings.

The data and results are presented in the form of a bles and curves, as in previous reports of the series. Detailed information is given in the tables in order that the reader may reduce the data by other methods or make other comparisons than those of this report.

APPARATUS AND METHODS

The tests were made in the N.A.C.A. 20-foot propeller-research wind tunnel, which is described in reference 6. The methods followed were the same as in previous tests of this series.

The wings used were of laminated wood with steel members for attaching nacelle supports. The Clark Y wing was 11.68 percent chord thick, 38 inches in chord, and 15 feet 10 inches in span (aspect ratio 5). Its dimensions are the same as those of the wing used in the tests of reference 3, but it was of solid instead of hollow construction. The two wings show a slight difference in airfoil characteristics when tested alone. The thick wing was the one used in the tests of references 1 and 2. Its maximum thickness was 20 percent of the chord, its chord length was 5 feet, and its span 15 feet (aspect ratio 3). The ordinates of the Clark Y section are available from many sources; those of the thick wing section are given in figure 1 of reference 1. The area of the Clark Y wing was 50 square feet and that of the thick wing, 75 square feet. The standard balance system of the tunnel, which is described in reference 6, and the airfoil supports described in reference 7, were used, the only modification being the use of a double sting, to clear the propeller.

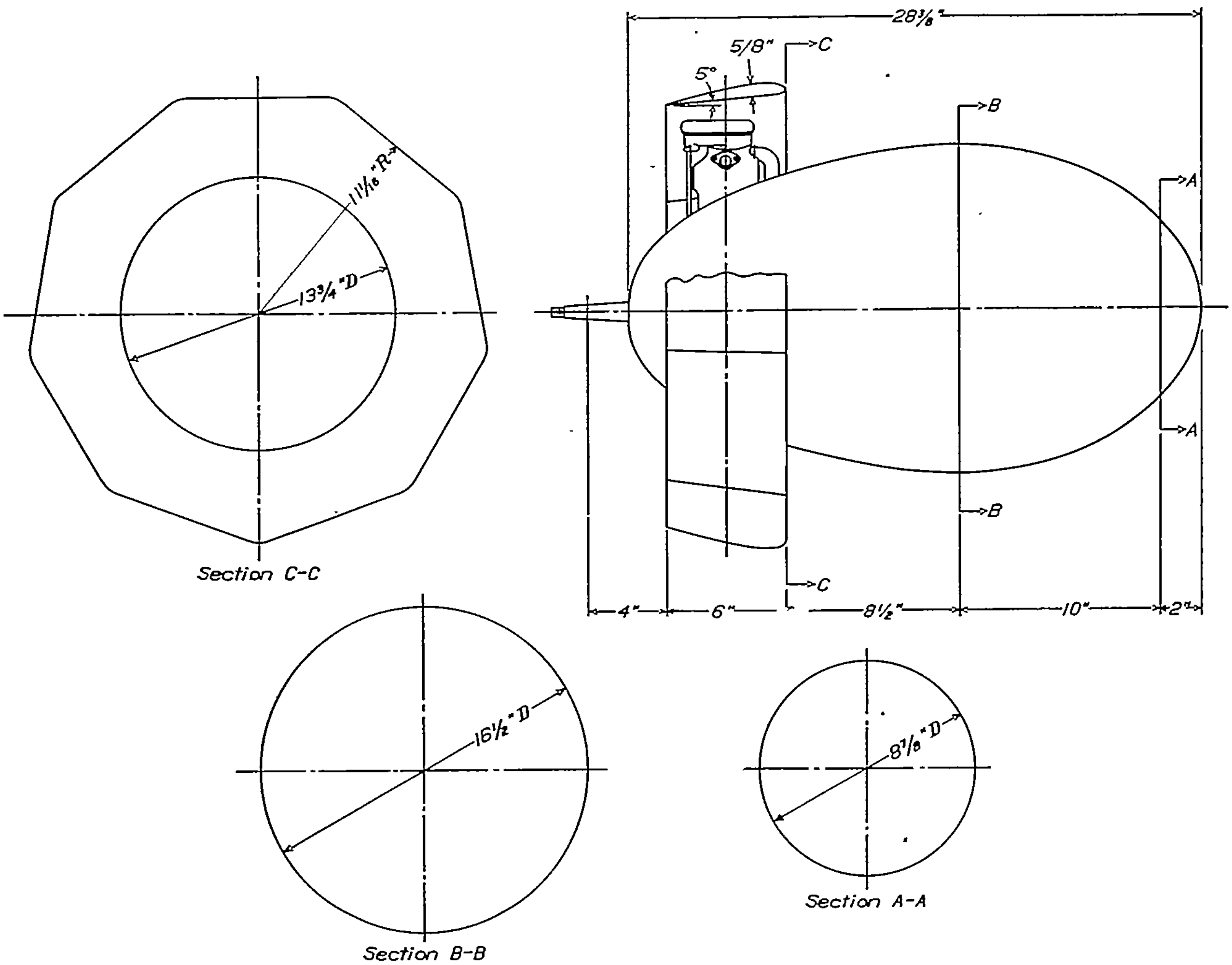

FIGURE 1.—Nacelle 1 and engine assembly with variable-angle ring set 5°.

Preliminary drag and propeller tests were made on nacelles alone. Two nacelle shapes were tested with a 4/9-scale wooden model of a Wright J–5 radial engine. The nacelles were of sheet aluminum and contained an electric motor for driving the propeller. Nacelle 1 is shown in figure 1. Nacelle 2 was of the same general form but smaller (length 23⅜ inches, maximum diameter 14 inches). Tests were also made with the engine

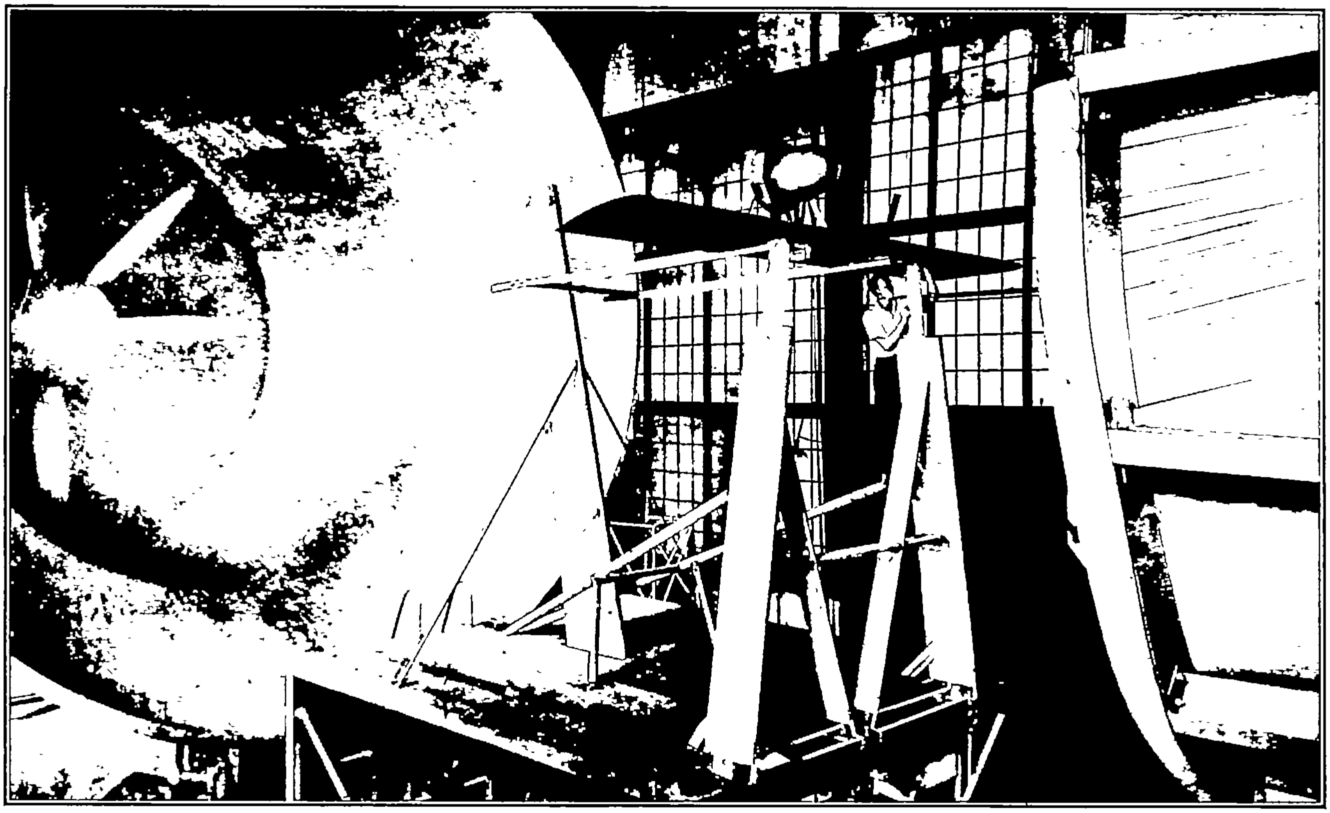

FIGURE 2.—Nacelle 1 with variable-angle ring set 5°, in position 5 on Clark Y wing. mounted for test.

model mounted on the bare electric motor. The motor shell was 10 inches in diameter and roughly ellipsoidal in shape. The engine model was tested on these three bodies, with exposed cylinders and with a variable-angle ring cowling set 0°, 5°, and 10°. A test was also made of the propeller and electric motor only. After these tests nacelle 1, with variable-angle ring cowling set 5°, was selected for testing with the wings. Although it appeared that a nacelle with a larger fore-body might be somewhat better, nacelle 1 was considered satisfactory for use in this investigation. A hole cut in the nose of the nacelle to provide ventilation for the electric motor produced no appreciable effect on the drag.

A 220-volt alternating current 3-phase induction motor, delivering 25 horsepower at 3,600 r.p.m., was used for driving the propeller. It was of special design, of unusually small size for its power. Speed control was obtained by changing the frequency. A condenser tachometer was used to determine the revolution speed. The power output of the motor was determined by calibration before the tests. A 4-foot-diameter aluminum-alloy propeller was used, which was geometrically similar to the Navy No. 4412, 9-foot-diameter propeller. The pitch could be adjusted by turning the blades in the hub; for these tests the blades were set 17° at 0.75 of the tip radius.

A photograph of the Clark Y wing with nacelle 1 mounted for test in the tunnel is shown in figure 2. Nacelle 1, with the variable-angle ring cowling set 5°, was tested in the 17 positions relative to the Clark Y wing shown in figure 3. The crosses in the figure indicate the position of the center line of the propeller. Photographs of the wing and nacelle in the various relative positions are shown in figures 4, 5, and 6. The same nacelle and cowling were tested in the three

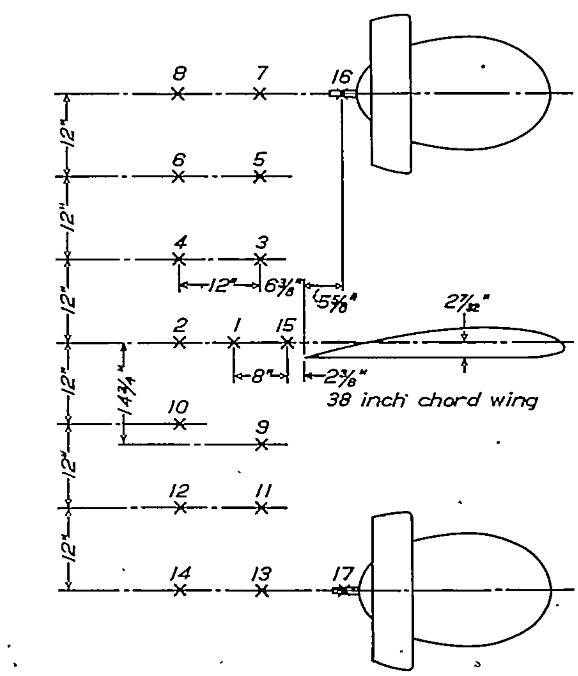

FIGURE 3.—Nacelle test locations with reference to Clark Y wing.

FIGURE 4.—Nacelle above and behind Clark Y wing in positions 1 to 8.

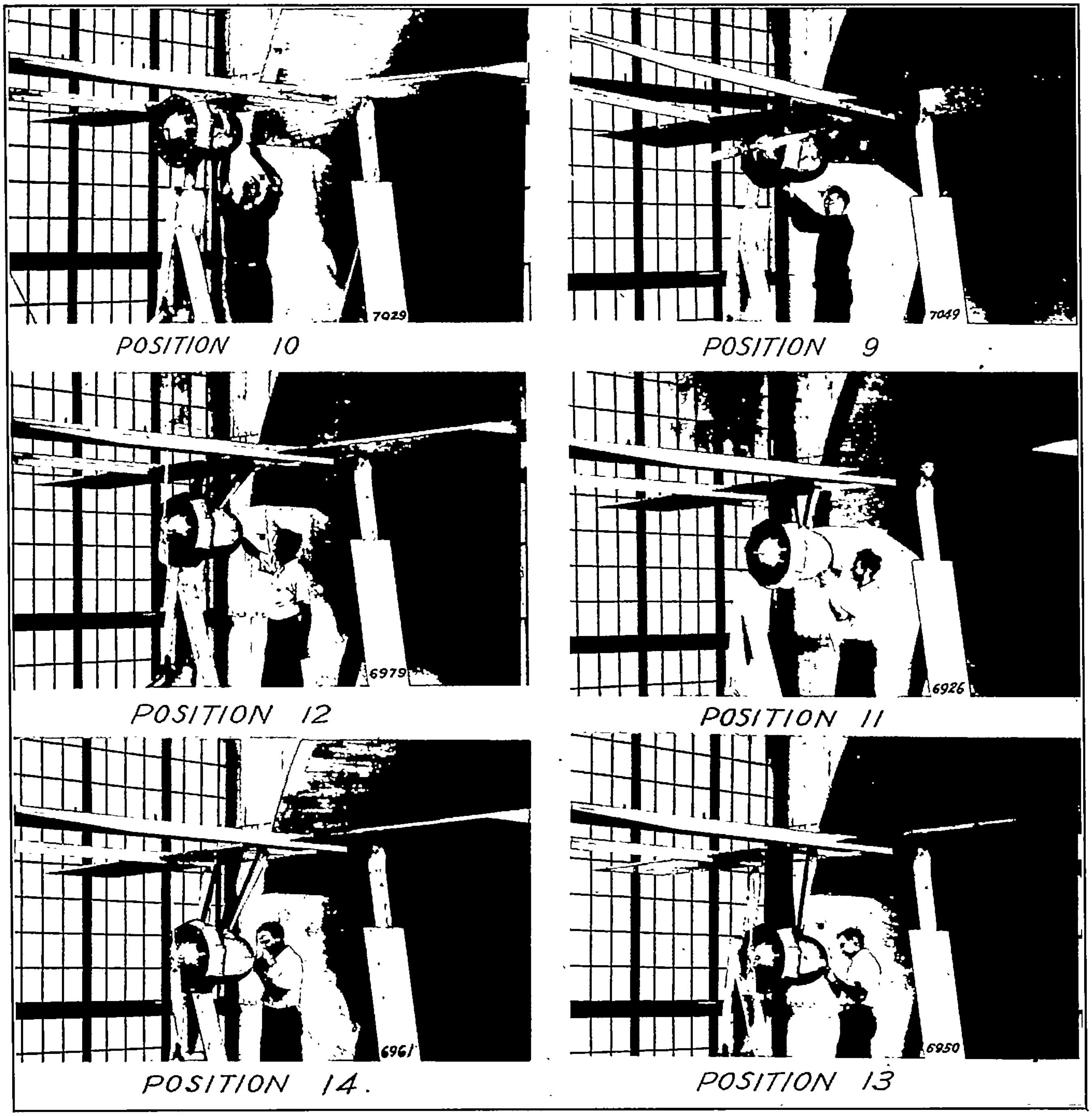

FIGURE 5.—Nacelle below Clark Y wing in positions 9 to 14.

representative locations (2, 7, and 13) with reference to the thick wing indicated in figure 7. Photographs of the wing and nacelle mounted in these three positions are shown in figure 8. The arrangement of the propeller and electric motor only, mounted in two positions directly behind the thick wing, is shown in figure 9. The nacelle and model engine were removed and the electric motor faired into the wing, the resulting body being similar to the body covering the supports of an extension shaft from an engine enclosed in the wing. Photographs of the wing with the propeller in positions 1 and 2, directly behind the wing, are reproduced in figure 10.

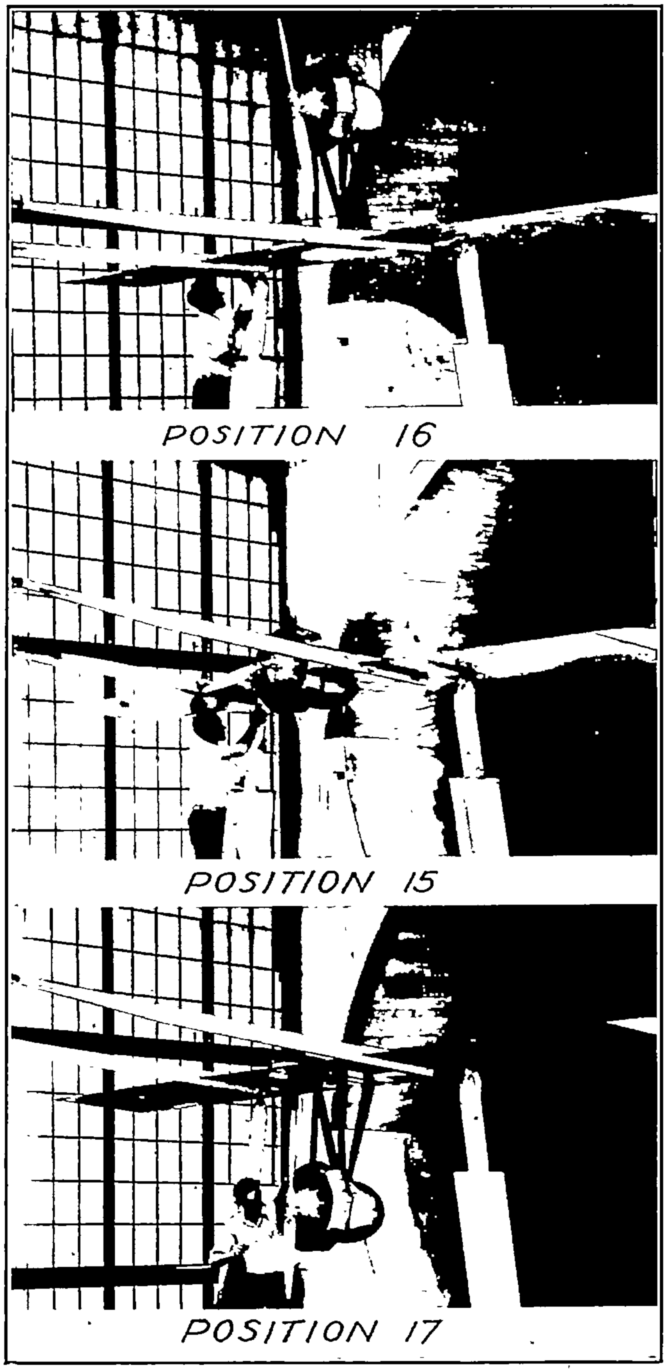

FIGURE 6.—Nacelle in forward locations above, below, and close behind Clark Y wing. Positions 15, 16, and 17.

The nacelle was supported in positions above and below the wings by struts of streamline tubing, except in positions 3, 4, 9, and 10, where the nacelle was carried by two vertical plates of ¼-inch steel. The supports for the nacelle in positions in line with the wing consisted of longitudinal steel members completely enclosed in the wing and nacelle.

Each wing-nacelle combination was first tested with the propeller removed, at 9 air speeds from 50 to 100 miles per hour, and at 5 angles of attack. Observations of lift, drag, and pitching moment were made. A test was then made with the propeller operating. The air speed and propeller revolution speed were varied to cover the useful range of V/nD, and net thrust, torque, propeller revolution speed, lift, and air speed were observed. This test was made at angles of attack of $-5°$, $0°$, $5°$, and $10°$, with the Clark Y wing combinations, and at $-5°$, $0°$, and $5°$, with the thick wing combinations. Both wings were also tested alone.

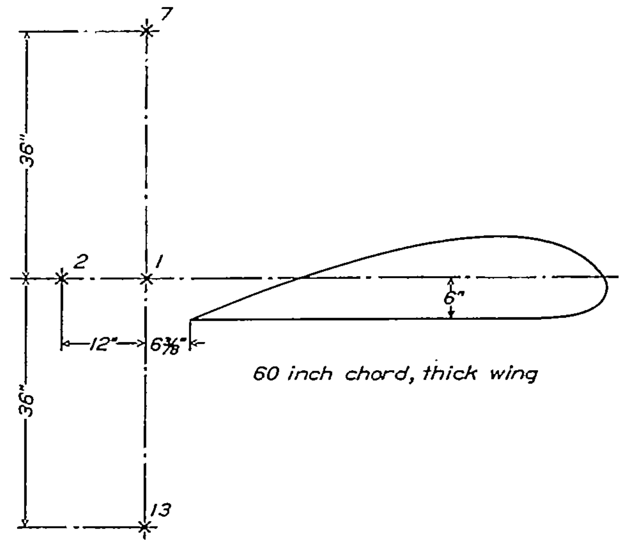

FIGURE 7.—Nacelle test locations with reference to thick wing.

Tare drag and tare lift were determined by tests with the wings suspended by wires in the usual position, but free from the normal supports. Previous tests indicated that the effect of the nacelle and propeller on the tare values was negligible.

RESULTS

The results of the tests with the propeller removed were reduced to the usual coefficients

$$C_L = \frac{\text{lift}}{qS}$$

$$C_D = \frac{\text{drag}}{qS}$$

$$C_m = \frac{\text{moment}}{qSc}$$

where

q, the dynamic pressure ($\frac{1}{2}\rho V^2$).
ρ, the mass density of the air.
V, velocity.
S, area of the wing.
c, chord of the wing.

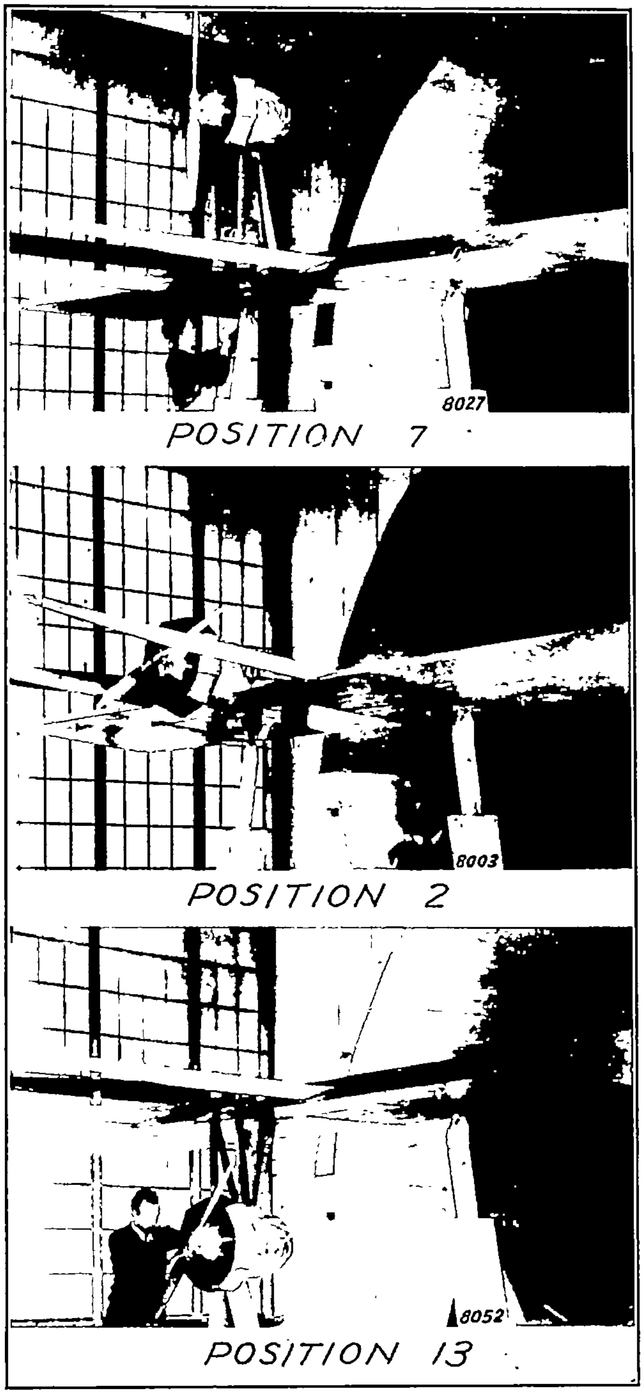

FIGURE 8.—Nacelle above, behind, and below thick wing.

(Moments are taken about the quarter-chord point of the wing.) The coefficients were plotted first against q and then cross-plotted against α for values of q corresponding to 50, 75, and 100 miles per hour. The value of C_m was found not to vary with air speed. The results of the tests with the propeller removed are presented in tables I, II, III, IX, and X. Polar curves for the Clark Y wing alone, and with the nacelle in commonly employed positions above, below, and directly behind the wing, are shown in figure 11. Similar curves are given in figure 12 for the best nacelle position found above, below, and directly behind the Clark Y wing. Figure 13 shows polars for the thick wing alone and with the nacelle in commonly employed positions above, below, and behind the wing.

The results of tests with the propeller operating were reduced to the following coefficients

$$C_T=\frac{T-\Delta D}{\rho n^2 D^4}$$

$$C_P=\frac{P}{\rho n^3 D^5}$$

$$\eta=\text{propulsive efficiency}$$

$$=\frac{\text{effective thrust}\times\text{velocity of advance}}{\text{motor power}}$$

$$=\frac{(T-\Delta D)V}{P}$$

$$=\frac{C_T}{C_P}\frac{V}{nD}$$

where T, thrust of propeller.

ΔD, change in drag of body due to action of propeller.

$T-\Delta D$, effective thrust. (See reference 8.)

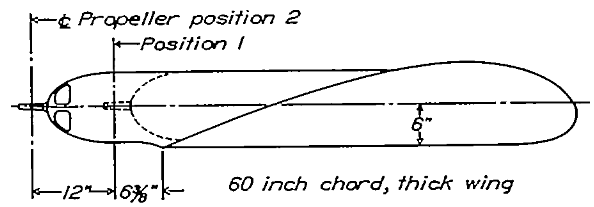

FIGURE 9.—Outline of electric motor faired into thick wing in positions 1 and 2.

Lift and moment coefficients are computed as before, but are now called C_{L_P} and C_{m_P}. The coefficients C_T, C_P, η, C_{L_P}, and C_{m_P} were plotted against V/nD, and values taken from the faired curves are given in tables IV to VIII for tests with the Clark Y wing, and tables XI to XV for tests with the thick wing. Curves of C_T, C_P, and η are given in figure 14 for commonly employed nacelle positions above, below, and directly behind the Clark Y wing. Similar curves are shown in figure 15 for the best position found above, below, and behind the Clark Y wing. Figure 16 gives curves of C_T, C_P, and η, for the nacelle positions tested above, below, and directly behind the thick wing.

The results of the tests of the electric motor only, faired into the thick wing, with propeller removed, are given in tables IX and X. A polar curve of C_L and C_D for position 2 is shown in figure 17, curves for the wing alone and with nacelle 1 in position 2 are also given for comparison. The results of the propeller tests with the electric motor only, faired into the thick wing, in positions 1 and 2, are given in tables

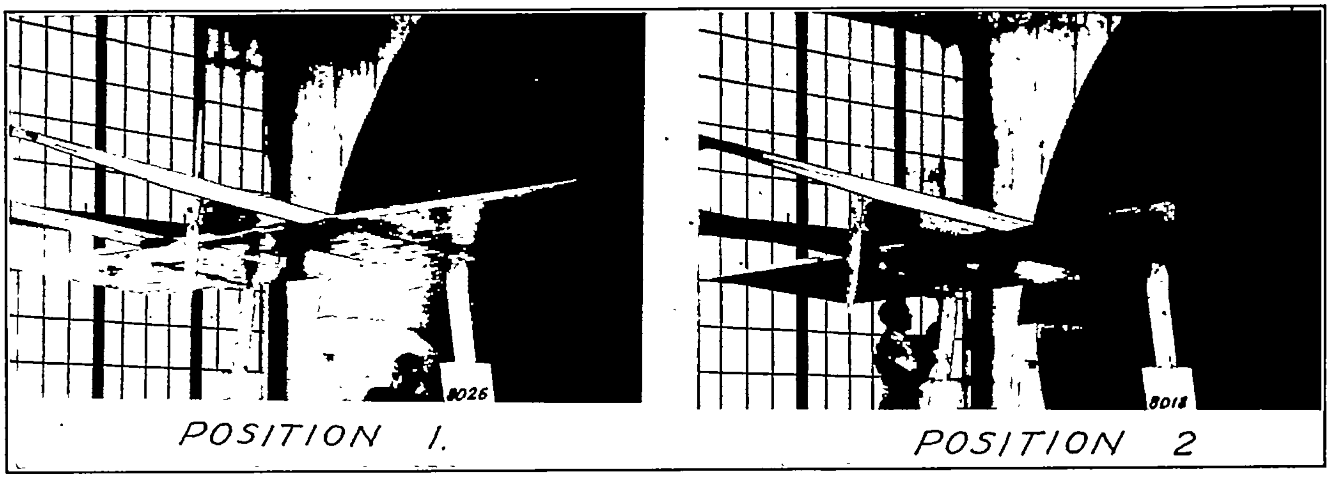

FIGURE 10.—Electric motor faired into thick wing in positions 1 and 2.

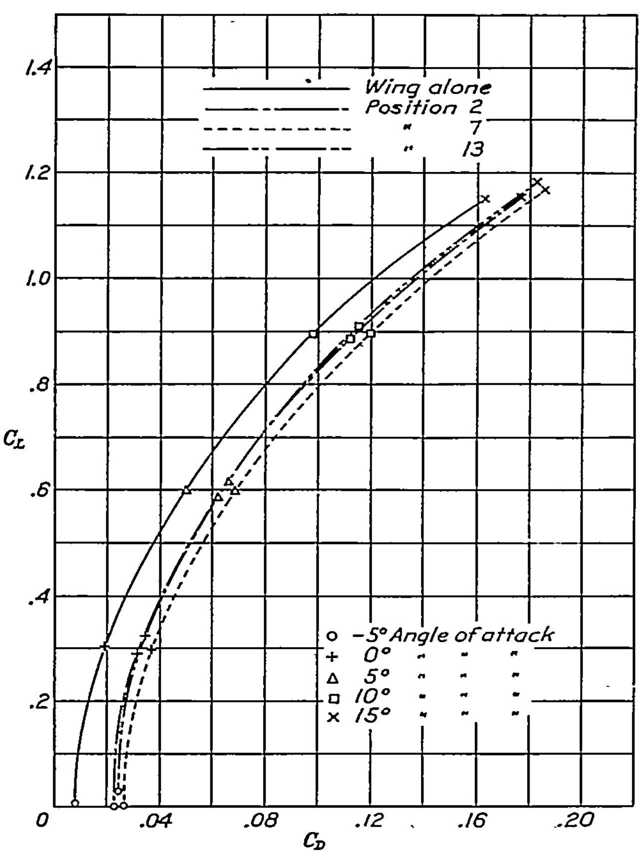

FIGURE 11.—Comparison of lift and drag characteristics of Clark Y wing alone, and with nacelle in positions 2, 7, and 13.

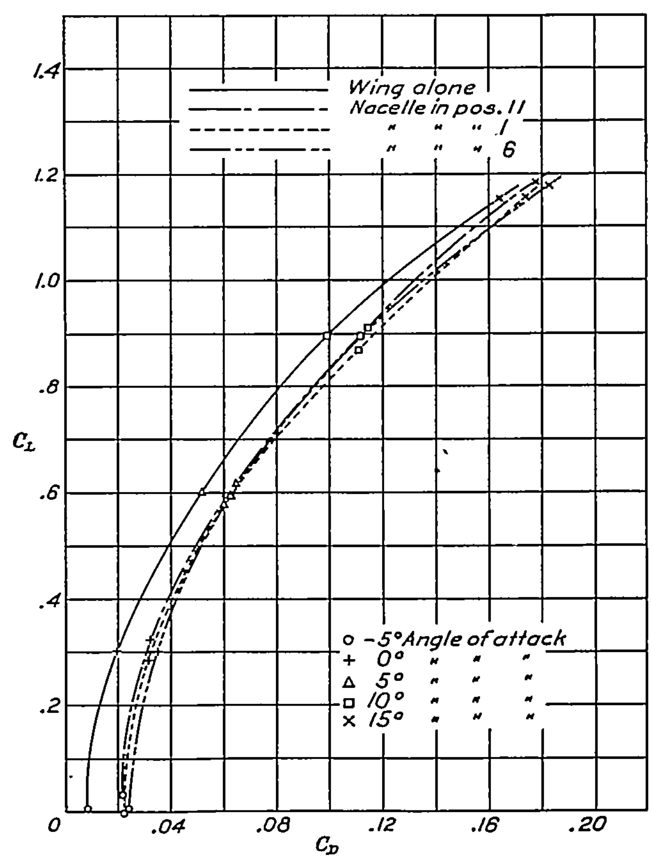

FIGURE 12.—Comparison of lift and drag characteristics of Clark Y wing alone, and with nacelle in positions 1, 6, and 11.

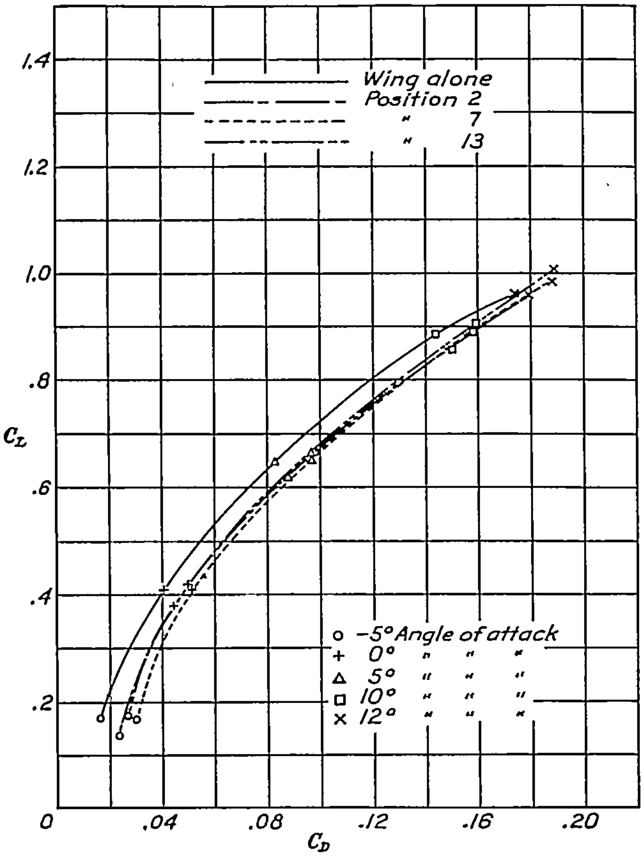

FIGURE 13.—Comparison of lift and drag characteristics of thick wing alone, and with nacelle in positions 2, 7, and 13.

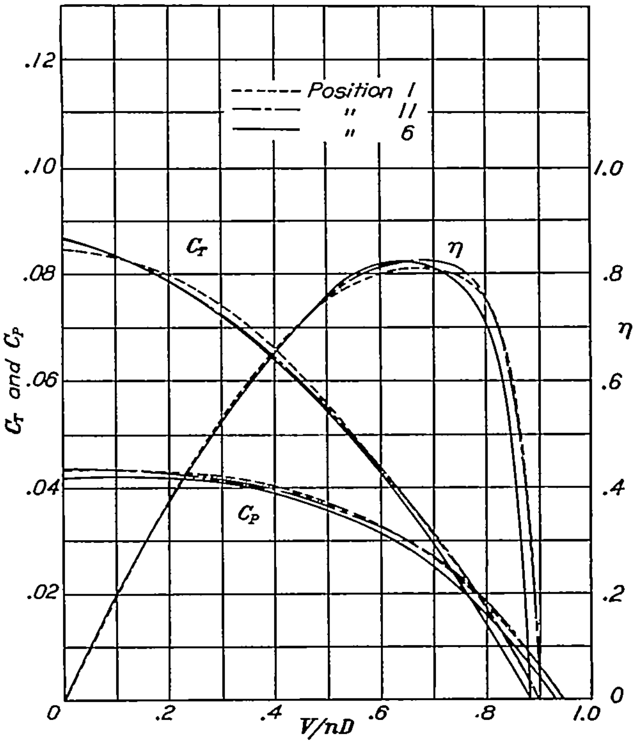

FIGURE 15.—Propeller characteristics with nacelle in positions 1, 6, and 11, on Clark Y wing. Angle of attack=0°.

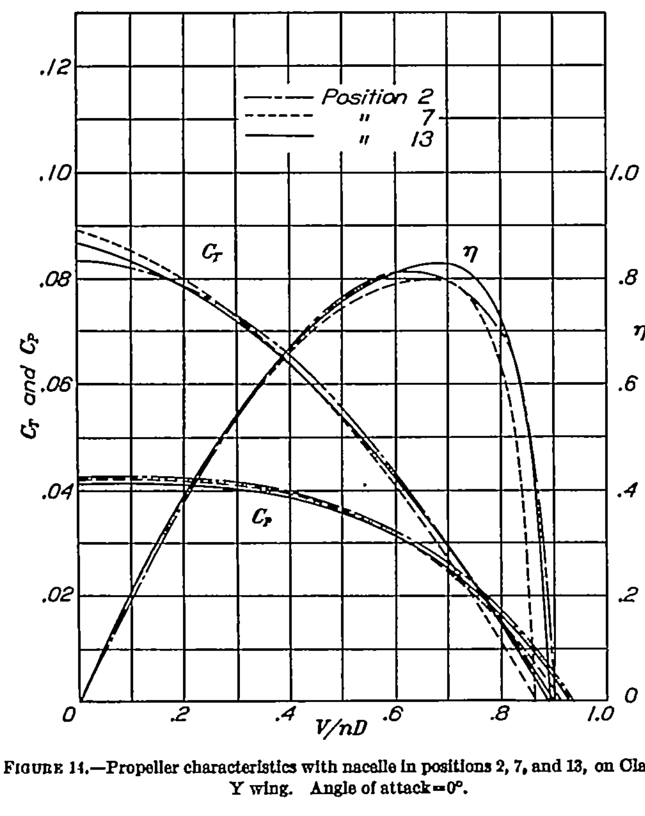

FIGURE 14.—Propeller characteristics with nacelle in positions 2, 7, and 13, on Clark Y wing. Angle of attack=0°.

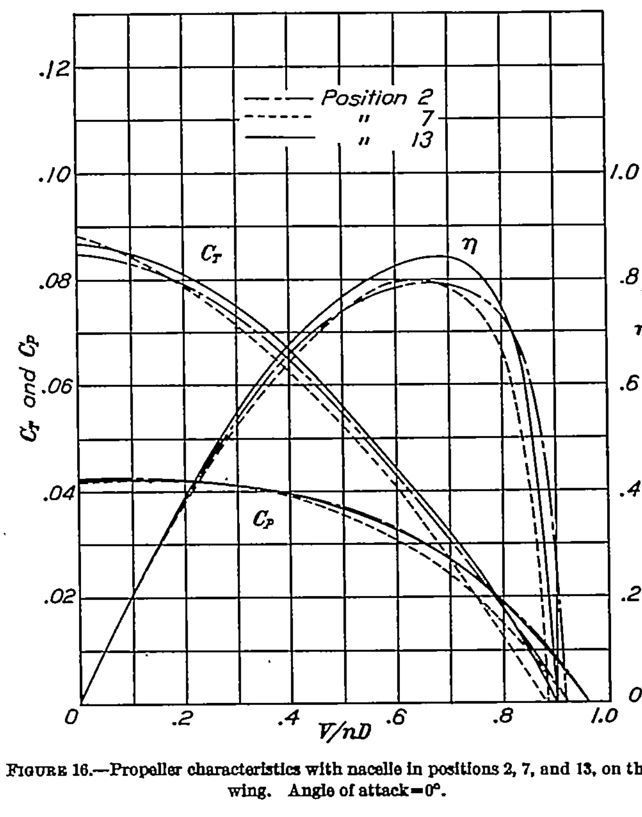

FIGURE 16.—Propeller characteristics with nacelle in positions 2, 7, and 13, on thick wing. Angle of attack=0°.

XI to XV. Figure 18 shows curves of C_T, C_P, and η for the electric motor only, faired into the thick wing in position 2. The curves for nacelle 1 in position 2 are also given for comparison.

The results of the preliminary tests of nacelles alone are given in table XVI. The nacelle drag at 100 miles per hour, with propeller removed, maximum propulsive efficiency, and net efficiency at $V/nD=0.65$, are tabulated.

ACCURACY

The angles of attack of the airfoils were set to within 5′ of the desired angle by means of an inclinometer. The tachometer used was accurate to 10 r.p.m. The power calibration of the motor appears to be accurate to within 0.25 horsepower from the dispersion of test points on the calibration curves. The lift and drag balances were read with a precision of 1 pound. In some cases fluctuations of the balances at high angles of attack reduced the accuracy; however, the major part of the results from faired curves is believed to be correct within ±2 percent.

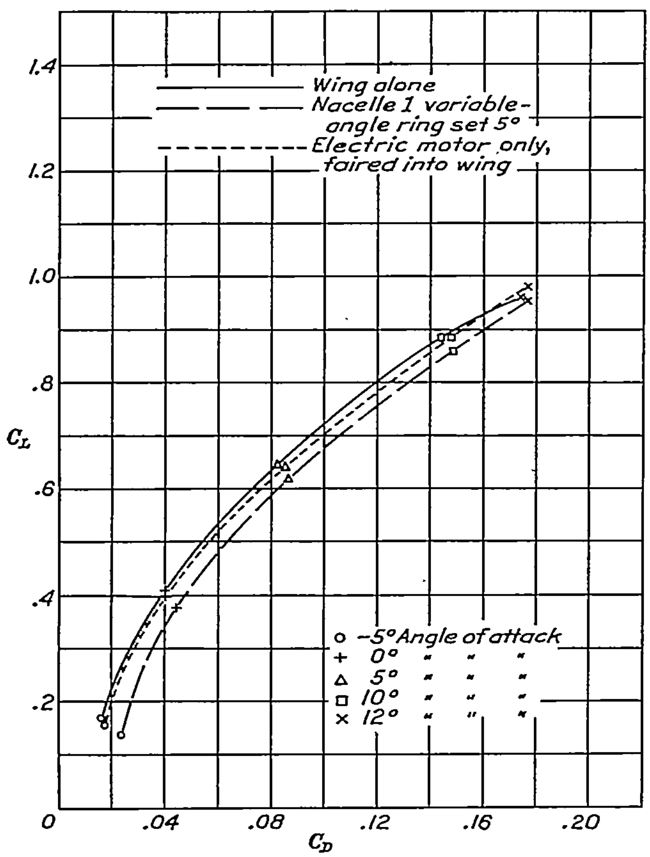

FIGURE 17.—Comparison of lift and drag characteristics of thick wing alone, with nacelle in position 2, and with electric motor only faired into wing in position 2.

DISCUSSION

The general problem of propeller, nacelle, and wing interference is complicated by the number of interdependent variables concerned. Mutual interference between wing and nacelle produces changes in lift and drag. Propeller characteristics are affected by the presence of the wing and nacelle and, in turn, lift, and drag of wing and nacelle are affected by the propeller slipstream, or inflow in the case of a pusher propeller. A comparision between wing-nacelle-propeller combinations should take all these effects into consideration, giving proper quantitative evaluation to changes of lift, drag, and propulsive efficiency in common terms.

NET EFFICIENCY

No method of determining the relative merit of a given combination has yet been found which is entirely satisfactory, or which is valid for all flight conditions. A method developed in reference 1, and further discussed in reference 3, compares various wing-nacelle-propeller combinations on the basis of three quantities—propulsive efficiency, nacelle drag efficiency factor, and net efficiency. The propulsive efficiency computed by this method was intended to represent the fraction of motor power available from the propeller for overcoming nacelle drag, interference drag, and drag of other parts of the airplane. The nacelle drag efficiency factor was intended to represent the fraction of motor power absorbed by nacelle drag and interference. The difference between these two quantities gave the net efficiency or the fraction of the motor power available for overcoming the drag of other parts of the airplane after propeller power losses and the power absorbed by nacelle drag and interference had been accounted for. The quantities entering into the problem were defined as follows:

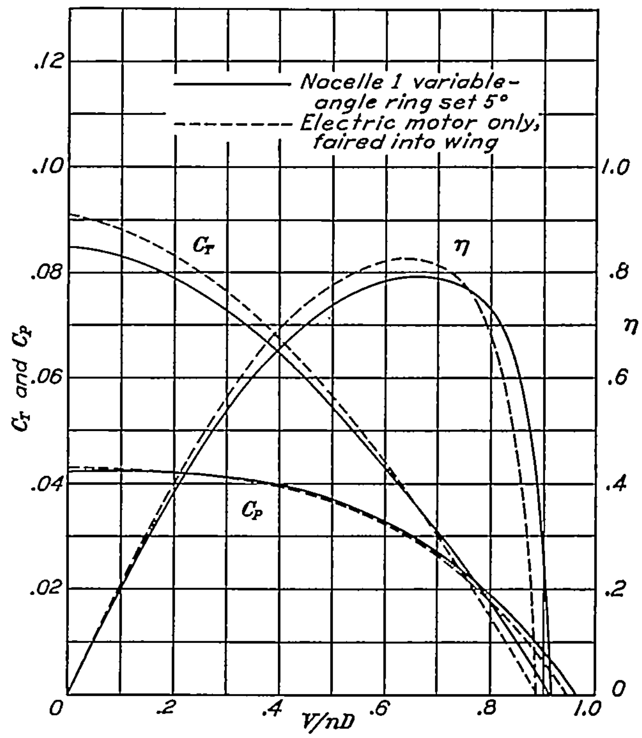

FIGURE 18.—Propeller characteristics with nacelle in position 2; and with electric motor only, faired into wing in position 2. Thick wing. Angle of attack=0°.

$$\text{Propulsive efficiency}=\eta=\frac{(T-\Delta D)V}{P}=\frac{C_T}{C_P}\frac{V}{nD}$$

Nacelle drag efficiency factor = N.D.F.

$$=\frac{(D_C-D_W)V}{P}=\frac{C_{D_C}-C_{D_W}}{C_P}\frac{S}{2D^2}\left(\frac{V}{nD}\right)^3$$

$$\text{Net efficiency}=\eta_0=\eta-\text{N.D.F.}$$

where C_{D_W}, the drag coefficient of the wing alone corresponding to a given lift coefficient.

C_{D_C}, the drag coefficient of the wing-nacelle combination with the propeller removed.

C_{D_C}, η, and C_P were taken at the angle of attack at which the lift coefficient of the combination, with the propeller operating, was equal to the given lift coefficient. The factor $\frac{S}{2D^2}\left(\frac{V}{nD}\right)$ converts the difference between drag coefficients to thrust-coefficient form.

In references 1, 2, and 3, the computation was performed in the following manner:

1. A value of lift coefficient and a value of V/nD were chosen as a basis for comparison.
2. C_{L_P}, C_P, and η for the chosen value of V/nD were plotted against angle of attack.
3. Values of η and C_P were then read from these curves at the angel of attack at which C_{L_P} was equal to the chosen value of the lift coefficient. The value of η was the propulsive efficiency used for purposes of comparison and the value of C_P was used in computing the nacelle drag efficiency factor.
4. C_{D_W} was taken at the chosen lift coefficient, and C_{D_C} was taken at the angle of attack at which C_{L_P} in the plot 2 was equal to the chosen lift coefficient. The difference between these drag coefficients was then used in computing the nacelle drag efficiency factor.
5. The net efficiency, η_0, was then taken as the propulsive efficiency from 3 minus the nacelle drag efficiency factor.

Although the results obtained by this method were fairly satisfactory, further study has brought up the question of the effect of induced drag and of wind-tunnel boundary interference on the propulsive efficiency and nacelle drag efficiency factor. Propulsive efficiency is defined as $\eta=\frac{(T-\Delta D)V}{P}$. In the experiments $T-\Delta D$ (effective thrust) is determined by adding to the thrust balance reading, the drag of the combination with the propeller removed at the same angle of attack. This is the customary method in which the resultant horizontal force R, with propeller operating, is considered to consist of three components

$$R=T-D-\Delta D$$

where T, the thrust of a propeller operating in the presence of a body.

D, the drag of the body with propeller removed at the same air speed and angle of attack.

ΔD, the increase in drag due to the action of the propeller.

The propeller is charged with the mutual interference between the body and the propeller, and the effective thrust is defined as

$$\text{Effective thrust}=T-\Delta D$$
$$=R+D$$

This method has proved quite satisfactory in testing propellers in conjunction with various bodies. When lifting surfaces are included in the system, however, the propeller produces changes in lift which are accompanied by changes in induced drag.

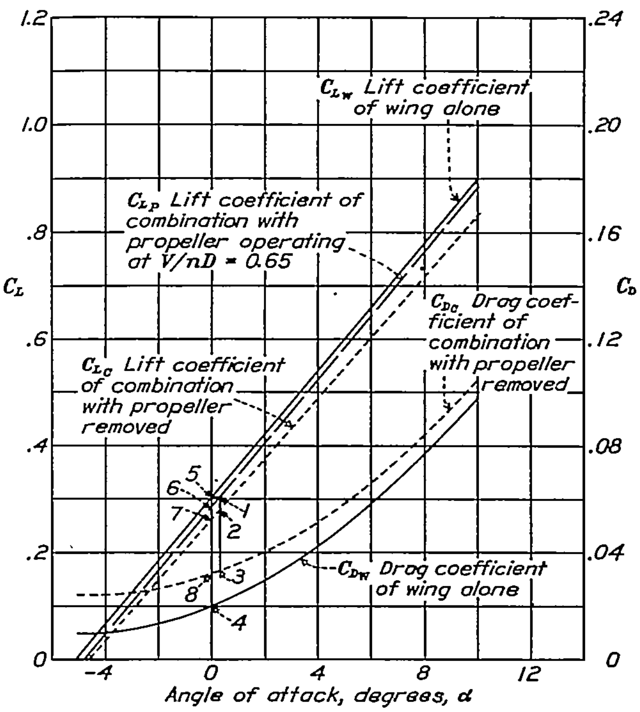

FIGURE 19.—Lift and drag coefficients of Clark Y wing alone, and with nacelle in position 15.

Since the experiments are performed in a wind tunnel the interference of the jet boundary appears as an additional induced drag so that ΔD is now made up of three parts: profile drag, induced drag, and jet-boundary interference drag,

or $$\Delta D=\Delta D_0+\Delta D_i+\Delta D_j$$

The effective thrust, and hence the propulsive efficiency, are therefore affected by any change in lift due to the action of the propeller.

The situation may be seen clearly by referring to figure 19, in which lift and drag coefficients of the wing alone and of a wing-nacelle combination are plotted. The lift coefficient of the combination with the propeller operating at $V/nD=0.65$ is also shown. In order to see how the propulsive efficiency and nacelle drag efficiency factor are affected, let the lift coefficient corresponding to 0° angle of attack of the wing alone be chosen as the basis for comparison as indicated at point 5. This value of lift coefficient is reached by C_{L_P} at 0.3° angle of attack, point 1. The drag of the combination with the propeller removed used in computing the effective thrust $(T-\Delta D)$ by the method discussed above, is at point 3 and the corresponding lift coefficient is at point 2. When the propeller is operating, the induced drag and jet-boundary interference drag are actually greater than they were at point 3 by the amount corresponding to the difference in the lift coefficients at points 1 and 2. Hence, the computed value of effective thrust is in error by this amount In this particular case the propulsive efficiency is too low by the amount $\frac{(\Delta D_i+\Delta D_j)V}{P}$ where ΔD_i and ΔD_j are the changes in induced drag and jet-boundary interference drag due to the increase in lift coefficient at point 1 over that at point 2, which is due to the action of the propeller.

The nacelle drag efficiency factor was computed from the difference between the drag coefficient of the combination at point 3 and that of the wing alone at point 4. The corresponding lift coefficients are at points 2 and 5. As the lift coefficient is lower for the combination with the propeller removed than for the wing alone, the nacelle drag efficiency factor as computed was too low by the amount $\frac{(\Delta D_i+\Delta D_j)V}{P}$ due to the difference between the lift coefficient of the wing alone at point 5 and of the combination at point 2. The lift coefficients at points 5 and 1 are equal; hence the error in nacelle drag efficiency factor is equal to the error in propulsive efficiency, and is of the same sign. As $\eta_0=\eta-$N.D.F. the errors cancel and net efficiency is not affected by the changes in induced drag and jet-boundary interference drag.

The corrections employed throughout this report, besides eliminating certain anomalous results such as negative nacelle drag efficiency factors that have appeared in the earlier published results, are of some importance in applying the data to design problems as will appear in a later section of this report.

The correction of the values of propulsive efficiency and nacelle drag efficiency factor as indicated above is not so easy as it might appear. The values of lift, drag, and propeller characteristics which enter the formulas are given in the tables at even values of angle of attack and V/nD for convenience and simplicity. In order to obtain the values required for a particular case several curves must be plotted from which the values required must be read. Although this is a matter of no difficulty, considerable labor is involved and it seems advisable to alter the equations so that the required corrected factors are obtained by substituting values directly from the tables in the formulas. Instead of correcting existing factors new ones are determined which contain the corrections with much less labor than is required in getting the correction itself. The advantage of using tabular values directly need not be elaborated upon and the new formulas required will now be developed.

METHOD OF COMPARISON

In order to eliminate the effect of induced drag and jet-boundary interference drag from propulsive efficiency and nacelle drag efficiency factor:

1. An angle of attack and a value of V/nD are chosen as a basis for comparison.
2. The value of η at this angle of attack and V/nD is then corrected for the effect of induced drag and jet-boundary interference.

$$\text{Corrected } \eta=\eta+\left[\frac{(\Delta C_{D_i}+\Delta C_{D_j})}{C_P}\ \frac{S}{2D^2}\left(\frac{V}{nD}\right)^3\right]$$

If 0° angle of attack and $V/nD=0.65$ are the chosen values, C_{L_P} is at point 6 in figure 19 and C_{L_C} is at point 7. These are the lift coefficients with the propeller operating and with the propeller removed, respectively. Then

$$\Delta C_{D_i}=\frac{(C_{L_P}{}^2-C_{L_C}{}^2)}{\pi\times\text{aspect ratio}} \tag{1}$$

and

$$\Delta C_{D_j}=\frac{\delta(C_{L_P}{}^2-C_{L_C}{}^2)S}{C} \tag{2}$$

in which C is the cross-sectional area of the jet. The value of C_P is taken at the chosen angle of attack and V/nD.

It will be noted that formula (1) is the usual one for induced drag with elliptical span loading.

In formula (2) for jet-boundary interference drag the value of δ depends on the ratio of the span of the wing to the jet diameter. The value of δ is 0.148 for the Clark Y wing and 0.142 for the thick wing of this series of tests. For discussion of jet-boundary interference see reference 9.

3. The nacelle drag efficiency factor is computed as,

$$\text{N.D.F.}=\frac{(C_{D_C}-C_{D_W})+(\Delta C_{D_i}+\Delta C_{D_j})}{C_P}\ \frac{S}{2D^2}\left(\frac{V}{n\,D}\right)^3$$

where C_{D_C} and C_{D_W} are at the chosen angle of attack (points 8 and 4 in fig. 19). The corresponding lift coefficients are C_{L_C} and C_{L_W} (points 7 and 5 in fig. 19), and the resulting changes in induced drag and jet-boundary interference drag are

$$\Delta C_{D_i}=\frac{C_{L_W}{}^2-C_{L_C}{}^2}{\pi\times\text{aspect ratio}}\ \text{ and }\ \Delta C_{D_j}=\delta\frac{(C_{L_W}{}^2-C_{L_C}{}^2)S}{C}$$

The value of C_P is taken at the chosen angle of attack and V/nD.

4. The net efficiency is then

$$\eta_0 = \text{corrected } \eta - \text{N.D.F.}$$

These three terms used to compare different wing-nacelle propeller combinations may now be described as follows:

1. Corrected η is the ratio of thrust power, less the loss due to increase in profile drag of wing and nacelle caused by the propeller, to the motor power.
2. N.D.F. is the ratio of power absorbed by nacelle drag and interference to the motor power.
3. η_0=corrected η−N.D.F. is the ratio of power available for overcoming drag of other parts of the airplane to the motor power.

The net efficiency η_0 is a measure of the real merit of the combination under the operating conditions chosen.

The approximation involved in correcting η lies in evaluating the change in induced drag and jet-boundary interference drag due to the change in lift when the propeller is operating. The equations for an elliptically loaded wing were used and, as the wings were rectangular in plan form and the load distribution affected somewhat by the presence of the nacelle and action of the propeller, an error enters. This error is a small part of the correction which is itself quite small; hence the error is probably well within the limits of experimental accuracy. A similar error is made in determining the nacelle drag efficiency factor but is, for the same reason, considered negligible.

The corrected propulsive efficiency, nacelle drag efficiency factor, and net efficiency have been computed at two sets of operating conditions for all the combinations tested. One set of conditions, 0° angle of attack and V/nD=0.65, corresponds to high-speed flight. This value of V/nD was the average at which maximum propulsive efficiency occurred. The other set of operating conditions, 5° angle of attack and V/nD=0.42, corresponds to climbing flight. This value of V/nD was determined by assuming that the best rate of climb occurs at a speed equal to 60 percent of the high speed and that the engine speed varies directly with the power, i.e., engine torque is constant. These conditions are the same as have been assumed in previous reports.

The net efficiencies given in this report may be compared directly with those given in references 1, 2, 3, and 5 but, as previously pointed out, the propulsive efficiencies and nacelle drag efficiency factors must be recomputed before they can be compared with those of this report.

Table XVII gives the corrected propulsive efficiencies, nacelle drag efficiency factors, and net efficiencies, computed for both conditions for all the combinations tested on the Clark Y wing. Table XVIII similarly gives the factors for the combinations tested on the thick wing.

Comparisons based on net efficiency as calculated in this report appear to be valid for application to airplanes with top speeds up to about 120 miles per hour with a J–5 engine. As speeds increase, nacelle and interference drag absorb an increasingly larger fraction of the engine power and drag becomes a more important consideration than propulsive efficiency.

RELATIVE MERITS OF NACELLE POSITIONS TESTED WITH CLARK Y WING

Considering the effects of the nacelle on lift and drag with the propeller removed, it appears from an examination of tables I and II and figures 11 and 12 that, in general, the nacelle below the wing increases the lift at a given angle of attack, whereas the nacelle above and directly behind the wing decreases the lift. In general, the drag is higher when the nacelle is placed above the wing than when it is below or directly behind the wing. Position 15, close behind the wing, is somewhat poorer than positions 1 and 2, which are farther back. On the basis of tests with the propeller removed positions, 6, 4, 1, 2, 9, 10, 11, 12, 13, 14, and 17 (see fig. 3) are all good, the region around 9, 10, and 11 being the best. On the same basis, position 3 and the top row, 7, 8, and 16, are definitely poor.

The relative merits of the nacelle positions, when the propeller is operating, may be judged by an examination of table XVIII, in which are tabulated the corrected propulsive efficiency, the nacelle drag efficiency factor, and the net efficiency of each position for both the high-speed and the climbing conditions. The net efficiency, as had already been stated, is equal to the corrected propulsive efficiency minus the nacelle drag efficiency factor, and is a measure of the merit. The variation of propulsive efficiency with nacelle location is small compared to the variation of nacelle drag factor.

In the high-speed condition the nacelle drag factor is low for positions 9, 10, 11, 1, and 2, and is high for all positions above the wing except 4. Position 11 has the highest net efficiency; 9 and 10, also below the wing, and 1 and 2, behind the wing, are nearly as good. Position 14 is also good, the high propulsive efficiency compensating for the high nacelle drag factor. In general, positions below the wing are better than positions above the wing. Of the positions in line with the wing, 1 and 2 are the best and are nearly as good as the best positions below the wing. Positions 6 and 4 are the best of those above the wing, being only a little poorer than 1 and 2. Position 3 is the worst of all those tested.

For the climbing condition, the variation of the factors with nacelle location is much smaller than for the high-speed condition, and the positions do not fall in the same order of merit as before Positions directly behind and above the wing have in general a lower nacelle drag factor than those below the wing. Apparently there is no consistent variation of net efficiency with nacelle location for this condition. Position 8 has the highest net efficiency, followed closely by positions 6 and 12. Position 3 is again the worst.

NACELLE AND THICK WING

The effects of the nacelle, tested with the propeller removed, in three representative positions relative to the thick wing, are shown in figure 13 and table IX. Position 13, below the wing, is best. The nacelle in position 2, directly behind the wing, has the lowest drag but has a detrimental effect on the lift. Position 7, above the wing, is the poorest. These results agree with those obtained with the Clark Y wing. When comparing the changes in lift and drag due to the nacelle on the two wings, it must be remembered that a wing area of 50 square feet was used in computing C_L and C_D for the Clark Y wing, and an area of 75 square feet for the thick wing.

The three nacelle locations may be compared, when the propeller is operating, by referring to table XVIII. In the high-speed condition position 13, below the wing, has the highest propulsive efficiency, and position 7, the lowest. Position 2 has the lowest nacelle drag efficiency factor, position 13 next, and position 7 the highest. The net efficiencies bear the same relationship as those of the corresponding positions tested on the Clark Y wing. Positions 2 and 13 are much better than 7. In the climbing condition, the differences between the factors for the three positions are much smaller. Position 13 has the best propulsive efficiency in this condition and 7 the best nacelle drag efficiency factor. The result is that there is little difference in the net efficiencies of the three nacelle locations for the climbing condition. Position 2 has the highest net efficiency, position 13 next, and 7 the lowest.

The results of the tests of the nacelle in three positions with reference to the thick wing are quite in accord with the results obtained with the nacelle in corresponding positions with the Clark Y wing. It therefore seems that the conclusions from all the Clark Y wing tests may be safely applied to a thick wing.

ELECTRIC MOTOR FAIRED INTO THICK WING SIMULATING AN EXTENSION PROPELLER SHAFT

The body formed by fairing the electric motor into the wing is perhaps somewhat larger than would be necessary to enclose the supports for an extension propeller shaft from an engine within the wing, but the results from these tests indicate what may be expected from such an arrangement. Table IX shows that the effect of the body with the propeller removed, on the lift and drag of the wing, is very small, and that near 0° angle of attack it is negligible. Figure 17 shows polar curves for the wing alone, with the electric motor only in position 2, and with nacelle 1 in position 2. The curve for the electric motor only in position 1 nearly coincides with that for position 2. On the basis of propeller-removed tests, this body is distinctly superior to nacelle 1 in any position.

Table XVIII shows that this arrangement is also very good when the propeller is operating. In the high-speed condition the propulsive efficiency is somewhat higher than it was with nacelle 1 in the same location, and the nacelle drag efficiency factor is very favorable, being quite small for both positions 1 and 2. These values result in a net efficiency much higher than was obtained with nacelle 1 in any position. In the climbing condition the same relationship is found, but the differences are much smaller.

COMPARISON OF PUSHER WITH TRACTOR COMBINATIONS

Nacelle 1 with variable-angle ring is comparable with the small tractor nacelle with variable-angle ring, tests of which are reported in references 2 and 3. These cowlings have rather high drag and do not represent the best obtainable design. Pusher nacelles are, however, more difficult to cowl completely than are tractor nacelles. A comparison will serve to show the relation between a tractor nacelle and a pusher nacelle with a similar type of cowling. The tractor nacelle and cowling mentioned above, and various other nacelles and types of cowling, are discussed in reference 10.

From the results obtained with the pusher nacelle and with the small tractor nacelle with variable-angle ring, both on the Clark Y wing (reference 3), the following conclusions may be drawn. When the propeller is removed, the pusher nacelle below the wing gives slightly higher lift than the tractor in a corresponding position, at low angles of attack. At high angles of attack the pusher nacelle gives higher lift than the tractor in all corresponding locations, above, below, and in line with the wing. There is little difference, otherwise, between pusher and corresponding tractor locations in their effect on the lift and drag. When the propeller is operating in the high-speed condition, the propulsive efficiency is, in general, about the same for the pusher as for the comparable tractor nacelle in a corresponding location. The nacelle drag efficiency factor of the pusher is better, for positions below the wing and about the same for positions above and in line with the wing, when compared with the tractor nacelle in corresponding positions. In general, the net efficiency of the pusher is better for positions below the wing, and poorer for positions in line with, and above the wing, than the tractor nacelle in corresponding locations. The nacelle in the best pusher position (11) has about the same net efficiency as the nacelle of comparable type in the best tractor position (B, reference 3). In the climbing condition the same general relations are found.

A comparison of the results obtained from tests of the pusher nacelle and thick wing, with the results given in reference 2 of tests of the small tractor nacelle with variable-angle ring cowling, shows that the relation between pusher and tractor is the same for the thick wing as for the Clark Y wing. The pusher appears to be a little better than the tractor when the nacelle is below the wing, and a little poorer when the nacelle is in line with, or above the wing.

The results given in references 1, 2, 3, and 10 show that an N.A.C.A. cowled tractor nacelle is much better than a nacelle with ring cowling of the type discussed above. For corresponding locations, the N.A.C.A. cowled tractor nacelle has a much higher net efficiency than the pusher nacelle of these tests. It seems likely, however, that an equally well cowled pusher nacelle would give results bearing the same relation to the N.A.C.A. cowled tractor nacelle that was found for the pusher nacelle tested and for the tractor nacelle with the same type of cowling.

Tests have been made with the electric motor only faired into the leading edge of the thick wing, and a comparison may be made with the corresponding tests of this report, which should indicate the relative merits of a tractor and a pusher propeller driven by an extension shaft from an engine within the wing. When the propeller is removed there is no appreciable difference in the effect of the body on the lift and drag in the two cases. The propulsive efficiency of the pusher is higher than that of the tractor in both high speed and climbing conditions. The nacelle drag efficiency factor of the tractor arrangement is, however, slightly better than that of the pusher, but the resulting net efficiencies are higher for the pusher arrangements than for the tractor in the high-speed condition and also in the climbing condition.

DESIGN CONSIDERATIONS

The net efficiencies and nacelle drag efficiency factors given in this report are approximately correct for airplanes with top speeds in the neighborhood of 100 to 140 miles per hour (depending on the engine size and power). At higher speeds higher propeller pitches are required, with a resulting increase in propulsive efficiency. The nacelle drag efficiency factor varies as the cube of V/nD; hence at higher speeds will be much larger. The net efficiencies will decrease as the speed increases.

Although the net efficiency in its present form is a useful criterion for comparing a number of combinations, in an actual design problem performance may be estimated more readily by converting the nacelle drags and interferences here given to coefficients based on the cross-sectional area of the nacelle. This conversion is accomplished by correcting the difference between the drag coefficient of the combination and of the wing alone for the difference in induced drag and jet-boundary interference in the two cases, and multiplying by the ratio of wing area to nacelle cross-sectional area. A coefficient is then obtained which may be applied to a nacelle of any diameter. The drag due to the nacelle and to interference may then be added to the drag of the rest of the airplane, for performance calculations.

In the calculation of the power available the corrected propulsive efficiency may be used. The increase in propulsive efficiency at higher pitches may be estimated from an examination of the charts of reference 8. Such a procedure will give a good estimate of the performance to be expected from a given design. A closer estimate is of course obtained by using the actual data. The following examples are therefore worked out in detail for a few of the best arrangements for which complete data are available, in order to illustrate the points made in the preceding paragraphs. They also show some rather interesting practical results.

EXAMPLES

Given a low-wing transport-type monoplane with two engines. To determine the high speed with three different engine locations.

The principal characteristics are:

Airplane:

- Weight, 17,500 lb.
- Span, 85 ft.
- Wing area, 948.6 sq. ft. (Tapered wing N.A.C.A. 2215 airfoil at root, 2209 at tip.)
- Parasite-drag coefficient $C_{D_p}=0.0203$ (including wing but excluding engine nacelles).

Two engines:

- Type, radial air-cooled.
- Power, 710 hp. each at 1,900 r.p.m. at 8,000 ft. ($\rho=0.001869$ lb.-ft.$^{-4}$-sec.^{2}).
- Geared, 11:16.
- Diameter, 53.75 in.

The equation for speed may be written in the familiar form

Power available = power required

$$\text{t.hp.}=\frac{\text{drag}\times\text{velocity (ft./sec.)}}{550} \tag{1}$$

or

$$\eta\times\text{b.hp.}=\frac{\text{drag}\times\text{velocity (ft./sec.)}}{550} \tag{2}$$

In the usual solution of this equation the drag is that of all parts of the airplane and η is the propulsive efficiency. In the present solution, however, the drag is taken for all parts of the airplane exclusive of the engine nacelles and the net efficiency is used instead of the propulsive efficiency. The nacelle drag is included as a reduction in efficiency instead of as an increase in drag as in the usual method. Unfortunately η cannot be simply expressed as a function of speed and a direct solution of equation (2) is not, in general, possible. Two or three trials will, however, usually give the correct solution.

Let D_A = drag of the airplane exclusive of engine nacelles

then

$$D_A = \text{parasite drag} + \text{induced drag}$$

$$= C_{D_P}\, qS + \frac{L^2}{\pi q b^2} \qquad (3)$$

where

b = span (more accurately effective span);
L = lift = weight

Substituting

$$D_A = 0.0203 \times \frac{0.001869\, V^2}{2} 948.6 + \frac{(17.500)^2}{\pi \frac{0.001869\, V^2}{2} \times (85)^2}$$

$$= 0.01795\, V^2 + \frac{14{,}460{,}000}{V^2} \qquad (4)$$

Values of D_A determined from this equation are used in all succeeding parts of the problem.

The next step is to determine the net efficiencies of the nacelle arrangements for which a comparison is desired. It is evident from the nature of this problem that the propeller pitch will be higher than the 17° previously discussed and it is necessary to set down some additional information for higher propeller pitch settings. Tests have not been made throughout a large range of settings for all arrangements, but for those to be compared results are available and are here given in a form more suited to the problem. Complete data will be published later.

As is set forth in reference 8, a convenient method of selecting a propeller for a given application is by the use of a coefficient $C_S = \sqrt[5]{\frac{\rho V^5}{P n^2}}$ As this coefficient does not contain the diameter, a plot of C_S against V/nD may be used to determine the diameter required to give the best efficiency for a given set of operating conditions as is clearly indicated in the reference cited. For the present purpose a plot of the envelop of the efficiency curves for various pitch settings against C_S and an auxiliary plot of V/nD against C_S for points on this envelop are sufficient since only the high speed is under discussion. In an actual design the performance under other flight conditions is required but such analysis as is required for these matters will not be discussed here.

Case I:

N.A.C.A. cowled nacelle in tractor position B of reference 1. This nacelle arrangement represents the best tractor-propeller arrangement for a cowled radial air-cooled engine so far discovered.

From the data of reference 1 and other results as yet unpublished the curves I are plotted in figure 20. Corrections to the measured data have been made to include the induced drag effects of propeller lift and jet-boundary interference in accordance with the method discussed earlier in this report. The data are given for an angle of attack of 0°.

Inserting values in the lift equation

$$C_L = \frac{\text{weight}}{\frac{1}{2}\rho V^2 S} = \frac{17{,}500}{\frac{0.001869}{2} \times 948.6 \times (308)^2} = 0.208$$

assuming tentatively a speed of 210 m.p.h. or 308 ft. per sec. For an airfoil of the N.A.C.A. 2200 series of aspect ratio 6 this lift coefficient is obtained at an

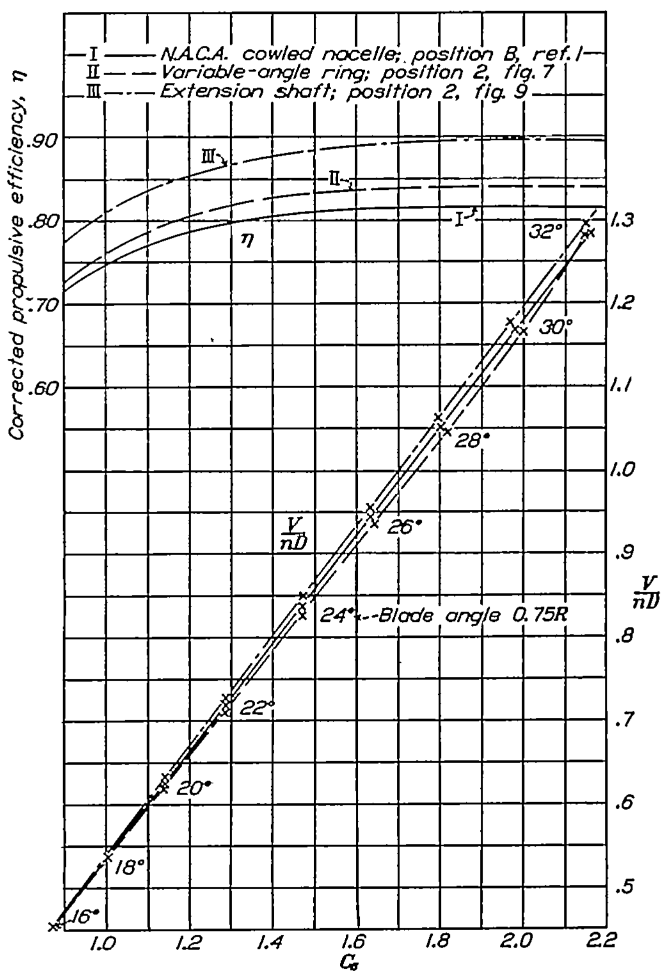

FIGURE 20.—Propeller characteristics for several nacelle positions used in examples. Angle of attack, 0°, propeller no. 4412.

angle of attack of 1.00° (reference 11). The actual aspect ratio is

$$A.R. = \frac{(\text{span})^2}{\text{area}} = \frac{(85)^2}{948.6} = 7.54$$

The induced angle for change of aspect ratio from 6 to 7.54 at $C_L = 0.208$ is

$$\Delta\alpha_i = \frac{C_L}{\pi}\left(\frac{1}{7.54} - \frac{1}{6}\right) 57.3 = -0.01°$$

The resultant angle of attack (0.99°) is sufficiently close to 0° for the purposes of this problem.

Continuing the assumption of $V=308$ ft. per sec. and assuming also a 3-bladed propeller, C_S may be computed from the values given above.

$$\text{hp.}=\frac{2}{3}\times 710=473 \quad \text{(3-bladed propeller)}$$

$$n=\frac{11}{16}\times\frac{1{,}900}{60}=21.8 \text{ r.p.s. (11:16 gear)}$$

$$C_S=\sqrt[5]{\frac{\rho V^5}{Pn^2}}=\sqrt[5]{\frac{0.001869\times(308)^5}{473\times 550\times(21.8)^2}}=2.12$$

From figure 20 curve I at $C_S=2.12$

$$\eta=0.815,\ \frac{V}{nD}=1.256, \text{ blade angle}=31.5°$$

Solving for D

$$D=\frac{1}{1.256}\times\frac{308}{21.8}=11.25 \text{ ft.}=11 \text{ ft. } 3 \text{ in.}$$

From tables I and II of reference 1 at 0° angle of attack

$$C_{D_C}=0.0420 \quad C_{D_W}=0.0405$$

$$C_{L_C}=0.403 \quad C_{L_W}=0.409$$

The corrected nacelle drag coefficient may be written

$$(C_{D_C}-C_{D_W})+\left[\{(C_{L_W})^2-(C_{L_C})^2\}\times\left(\frac{1}{\pi A.R.}+\delta\frac{S}{A}\right)\right] \quad (5)$$

$$=(0.0420-0.0405)+0.14\{(0.409)^2-(0.403)^2\}$$

$$=0.0015+0.0007=0.0022$$

Using $\delta=0.142$, A.R.$=3$, $\frac{S}{A}=\frac{75}{314.1}$ from the tunnel test conditions as previously discussed. This drag coefficient now has to be converted from a wing-area base to an engine-diameter base and scaled to full size.

Model engine diameter = 20 in.

Full-size engine diameter = 53.75 in.

Then

Model wing area = 75 sq. ft.

$$\text{Effective nacelle drag}=C_DqS=0.0022\times 75\times\frac{(53.75)^2}{(20)^2}\times\frac{0.001869}{2}V^2$$

For $V=308$ ft. per sec. the drag of two nacelles = 211 lb

This value of nacelle drag could be added to the drag of the remainder of the airplane determined from equation (4) and the total drag used with the propulsive efficiency in the usual manner. Equality in the two sides of equation (2) will then show whether the correct speed has been assumed. This may be the simplest procedure but in order to show certain features of the net efficiency it will be computed and applied in the solution.

The nacelle drag efficiency factor is

$$\text{N.D.F.}=\frac{\text{power used by nacelle drag}}{\text{motor power}}$$

$$=\frac{\text{nacelle drag}\times\text{velocity}}{\text{motor b.hp.}\times 550}$$

$$=\frac{211\times 308}{710\times 2\times 550}=0.0833$$

Net efficiency $=\eta_0=$ propulsive efficiency—N.D.F.

$$=0.815-0.083=0.732$$

Rewriting equation (4) and substituting $V=308$ ft./sec.

$$D_A=0.01795\times(308)^2+\frac{14{,}460{,}000}{(308)^2}$$

$$=1{,}704+152$$

$$=1{,}856 \text{ lb.}$$

Substituting D_A and η_0 in equation (2)

$$0.732\ (710\times 2)=\frac{1{,}856\times 308}{550}$$

$$1{,}040=1{,}040$$

This equality indicates that the assumed speed is correct and that the high speed of the airplane in question with the cowled air-cooled engines ahead of the wing is, to a first approximation, 210 miles per hour.

Case II:

Engines located at rear of wing in position 2 of figures 7 and 8 with cowling ring set 5°. In this case the corrected effective drag coefficient of the nacelle is computed from equation (5) using data from table IX.

$$C_{D_C} \quad C_{\ W}=0.0075$$

Since this is considerably higher than that in the previous case the air speed will be assumed $V=200$ m.p.h. = 293.5 ft./sec.

Then

$$\text{Nacelle drag}=0.0075\times 75\times\frac{(53.75)^2}{(20)^2}\times\frac{0.001869}{2}\times(293.5)^2$$

Drag of two nacelles = 653 lb.

$$\text{N.D.F.}=\frac{653\times 293.5}{710\times 2\times 550}=0.245$$

$$C_S=2.12\times\frac{293.5}{308}=2.02$$

using the value 2.12 determined in case I.

Then

$\eta=0.840$ from curve II of figure 20 at $C_S=2.02$, the values given having been derived for this case in the manner already described.

$$\text{Net efficiency} = \eta_0 = \eta - \text{N.D.F.}$$
$$= 0.840 - 0.245 = 0.595$$

D_A is now determined by substituting the new speed (V=293.5 ft. per sec.) in equation (4)

$$D_A = 0.01795 \times (293.5)^2 + \frac{14{,}460{,}000}{(293.5)^2}$$
$$= 1{,}542 + 168$$
$$= 1{,}710$$

Substituting the values of η_0 and D_A in equation (2)

$$0.595\ (710 \times 2) = \frac{1{,}710 \times 293.5}{550}$$
$$845 = 912$$

The left-hand side representing the power available is the smaller number; hence the assumed speed is too high. Power required varies nearly as the cube of the speed and power available will change very little since the efficiency curve is quite flat. $\frac{845}{912} = 0.926$ say 0.93; $\sqrt[3]{0.93} = 0.976$ and $0.976 \times 200 = 195.2$. A new speed 195 m.p.h. (286 ft. per sec.) is assumed and the computation repeated or the results more simply obtained by proportion.

$$\text{Nacelle drag} = 653 \times \left(\frac{286}{293.5}\right)^2 = 620 \text{ lb.}$$
$$C_S = 2.02 \times \frac{286}{293.5} = 1.97$$
$$\eta = 0.840 \text{ (from fig. 20, curve II)}$$
$$\text{N.D.F.} = 0.245 \left(\frac{286}{293.5}\right)^3 = 0.227$$

Then

$$\eta_0 = 0.840 - 0.227 = 0.613$$
$$D_A = 1{,}542 \times \left(\frac{286}{293.5}\right)^2 + 168 \times \left(\frac{293.5}{286}\right)^2$$
$$= 1{,}465 + 177$$
$$= 1{,}642 \text{ lb.}$$

Again substituting in equation (2)

$$0.613\ (710 \times 2) = \frac{1{,}642 \times 286}{550}$$
$$870 = 854$$

These values indicate that the new speed is $100 \left(1 - \sqrt[3]{\frac{870}{854}}\right) = 0.7$ percent too low and the actual speed with this nacelle arrangement is 196 miles per hour.

Case III:

Engines of same characteristics located in the wing with extension shaft to the rear as in position 2 of figures 9 and 10.

From the values in table IX the corrected value

$$C_{D_C} - C_{D_W} = 0.0012 \text{ (method of case I)}$$

Proceeding as in cases I and II with successive speed assumptions for a speed of 220 m.p.h. = 322.8 ft. per sec. there results

$$\text{Nacelle drag} = 145.8 \text{ lb.}$$
$$\text{N.D.F.} = 0.0577$$
$$C_S = 2.22$$
$$\eta = 0.895 \text{ (fig. 20, curve III)}$$
$$\eta_0 = 0.895 - 0.0577 = 0.837$$
$$D_A = 1{,}870 + 139 = 2{,}009$$

Then in equation (4)

$$0.837\ (2 \times 710) = \frac{2{,}009 \times 322.8}{550}$$
$$1{,}189 = 1{,}180$$

The speed with this arrangement of engines is therefore 220 miles per hour. An additional check gives 219.5 miles per hour.

DISCUSSION OF EXAMPLES

Several interesting points are disclosed by the preceding examples. The net efficiency in case I is 0.732, whereas in reference 1 it was 0.752. Likewise, for case II the net efficiency is 0.613 and for case III 0.837, whereas in table XVIII the efficiencies for these cases are 0.646 and 0.839, respectively. The net efficiencies are all reduced as the speed is increased. The nacelle drag efficiency factor is proportional to the cube of the speed for a given power and nacelle arrangement, whereas the propulsive efficiency increases rather slowly as indicated in figure 20. The fact that the propulsive-efficiency increase in case III is somewhat greater accounts for the smaller loss in net efficiency. The nacelle drag efficiency factors have increased from 0.042 (corrected from reference 1) to 0.083 in case I; 0.177 (table XVIII) to 0.227 in case II, and 0.028 to 0.0577 in case III due to the increase in speed (and change in power). It is easily deduced that a speed would finally be reached where all the engine power would be used in nacelle drag. In fact, with some poor arrangements this speed occurs below 200 miles per hour, demonstrating that as higher speeds are sought greater refinement and reduction of drag must be made unless the power is to be increased enormously.

The important effects of drag reduction are shown by the increase in speed of 14 miles per hour due to the higher efficiency of the tractor arrangement and the further increase of 9.5 miles per hour by installing the engine in the wing. It is to be noted that these results are estimated directly from the model tests in the simplest manner to give comparable results. Too great a refinement of detail does not seem to be justified at the present time because the proximity of the fuselage, the change in shape of nacelle in practical construction, and the use of wings of different thickness, chord, and taper, among other considerations, introduce variations not covered by the experiments. The results are, nowever, sufficiently indicative of desirable future trends to enable designers to obtain improved performance.

As far as the present results are concerned, the air-cooled engine with pusher propeller and cowlings of the type now available suffers in comparison with the tractor-propeller arrangements. If the engine can be arranged in the wing the pusher propeller seems to offer advantages. Further study of possible improvements in cowling of radial engines is required as well as of the cooling arrangements with the engine in the wing in order that the one may be improved and that the other may not lose its advantage when practically developed. Further development of engines for use in the wing should also proceed without delay.

CONCLUSIONS

1. The most favorable location for a radial-engine pusher nacelle of the type tested, for high-speed flight, is with the thrust line about 60 percent of the chord length below the center line of the wing, and with the propeller between 10 percent and 30 percent of the chord length behind the trailing edge.

2. In the climbing condition one nacelle location has little advantage over another.

3. Because of the agreement between the results obtained from tests of a nacelle in three positions relative to the thick wing and results from corresponding tests with the Clark Y wing, it is concluded that the results of all the tests made with the Clark Y wing are, in general, applicable to a thick wing.

4. A radial-engine nacelle for pusher propeller with ring cowling is, in the most favorable position, about as good as a tractor arrangement with a similar type of cowling in the most favorable tractor position, but is inferior to the N.A.C.A. cowled nacelle in the best tractor position.

5. A pusher propeller driven by an engine enclosed in the wing is better than a tractor propeller driven in the same manner. Both are considerably better than any of the pusher or tractor radial-engine nacelles used in this series of tests.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *June 7, 1934.*

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TABLE I
LIFT COEFFICIENT WITHOUT PROPELLER
CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

$$C_L=\frac{\text{lift}}{qS}$$

	50 m.p.h. R.N.=1,360,000				75 m.p.h. R.N.=2,040,000				100 m.p.h. R.N.=2,720,000				
Angle of attack	−5°	0°	5°	10°	−5°	0°	5°	10°	−5°	0°	5°	10°	15°
Nacelle position													
1	−0.004	0.288	0.580	0.871	−0.004	0.288	0.580	0.871	−0.004	0.288	0.580	0.871	1.150
2	.000	.295	.598	.896	.000	.292	.594	.893	.000	.290	.588	.888	1.154
3	.000	.279	.563	.848	.000	.279	.561	.845	.000	.279	.559	.840	1.122
4	−.031	.272	.575	.874	−.023	.275	.575	.874	−.012	.280	.575	.874	1.152
5	.014	.311	.610	.909	.011	.307	.605	.903	.008	.301	.599	.895	1.158
6	.015	.311	.603	.900	.011	.307	.600	.898	.006	.301	.596	.895	1.178
7	.011	.309	.611	.909	.007	.305	.606	.902	.002	.299	.599	.897	1.169
8	.026	.320	.612	.904	.029	.319	.607	.897	.032	.317	.600	.886	1.168
9	.050	.349	.648	.949	.050	.347	.645	.942	.050	.344	.640	.937	1.198
10	.089	.382	.674	.962	.081	.375	.667	.957	.070	.364	.658	.951	1.235
11	.069	.353	.641	.928	.054	.341	.631	.921	.034	.324	.618	.910	1.185
12	.063	.357	.647	.939	.052	.347	.639	.932	.036	.333	.628	.923	1.214
13	.039	.332	.628	.920	.034	.329	.624	.917	.028	.324	.618	.912	1.181
14	.066	.351	.638	.920	.058	.343	.630	.914	.046	.332	.618	.905	1.189
15	−.014	.272	.555	.837	−.017	.268	.561	.835	−.021	.263	.546	.832	1.116
16	.051	.335	.619	.904	.044	.327	.611	.897	.033	.316	.600	.887	1.171
17	.030	.328	.622	.918	.028	.325	.619	.915	.025	.322	.616	.911	1.170
	WING ALONE												
	0.051	0.341	0.632	0.921	0.031	0.325	0.618	0.911	0.004	0.303	0.599	0.898	1.151

TABLE II
DRAG COEFFICIENT WITHOUT PROPELLER
CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

$$C_D=\frac{\text{drag}}{qS}$$

	50 m.p.h. R.N.=1,360,000				75 m.p.h. R.N.=2,040,000				100 m.p.h. R.N.=2,720,000				
Angle of attack	−5°	0°	5°	10°	−5°	0°	5°	10°	−5°	0°	5°	10°	15°
Nacelle position													
1	0.0260	0.0350	0.0605	0.1105	0.0240	0.0330	0.0600	0.1105	0.0225	0.0315	0.0595	0.1105	0.1635
2	.0245	.0340	.0625	.1120	.0339	.0330	.0625	.1120	.0230	.0315	.0620	.1120	.1770
3	.0300	.0385	.0655	.1135	.0285	.0375	.0655	.1135	.0265	.0365	.0650	.1135	.1785
4	.0270	.0340	.0620	.1100	.0260	.0330	.0615	.1100	.0240	.0320	.0610	.1100	.1645
5	.0290	.0390	.0685	.1165	.0275	.0375	.0675	.1165	.0260	.0360	.0660	.1160	.1785
6	.0285	.0380	.0675	.1165	.0265	.0365	.0655	.1145	.0240	.0345	.0625	.1115	.1830
7	.0320	.0425	.0725	.1235	.0300	.0400	.0710	.1220	.0270	.0370	.0685	.1195	.1860
8	.0300	.0410	.0695	.1180	.0290	.0395	.0685	.1175	.0280	.0375	.0665	.1165	.1840
9	.0240	.0370	.0660	.1185	.0230	.0355	.0655	.1185	.0220	.0330	.0650	.1185	.1830
10	.0285	.0405	.0720	.1220	.0260	.0385	.0705	.1210	.0225	.0360	.0685	.1200	.1905
11	.0260	.0345	.0650	.1135	.0240	.0335	.0645	.1135	.0215	.0325	.0640	.1135	.1780
12	.0270	.0375	.0685	.1180	.0255	.0365	.0680	.1175	.0240	.0350	.0670	.1170	.1825
13	.0280	.0375	.0680	.1175	.0265	.0360	.0670	.1165	.0245	.0345	.0660	.1150	.1825
14	.0290	.0395	.0700	.1185	.0270	.0375	.0685	.1180	.0240	.0350	.0660	.1175	.1820
15	.0260	.0345	.0595	.1060	.0250	.0335	.0590	.1055	.0240	.0320	.0585	.1050	.1690
16	.0310	.0425	.0740	.1245	.0300	.0410	.0720	.1235	.0280	.0385	.0690	.1225	.1875
17	.0290	.0380	.0675	.1180	.0275	.0365	.0665	.1170	.0260	.0350	.0660	.1155	.1810
	WING ALONE												
	0.0102	0.0220	0.0501	0.1001	0.0095	0.0211	0.0500	0.0992	0.0084	0.0198	0.0499	0.0980	0.1633

TABLE III
MOMENT COEFFICIENT WITHOUT PROPELLER

$$C_m=\frac{\text{moment}}{qSc}$$

CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

Nacelle position	Angle of attack				
	−5°	0°	5°	10°	15°
1	−0.096	−0.092	−0.082	−0.077	−0.075
2	−.091	−.090	−.085	−.083	−.080
3	−.105	−.101	−.090	−.088	−.085
4	−.097	−.095	−.085	−.084	−.080
5	−.098	−.087	−.085	−.073	−.065
6	−.094	−.087	−.082	−.077	−.084
7	−.087	−.079	−.079	−.083	−.077
8	−.084	−.080	−.079	−.073	−.075
9	−.096	−.095	−.081	−.074	−.073
10	−.097	−.086	−.081	−.076	−.079
11	−.102	−.094	−.091	−.075	−.078
12	−.103	−.090	−.089	−.088	−.087
13	−.107	−.104	−.101	−.082	−.092
14	−.107	−.094	−.098	−.087	−.087
15	−.088	−.082	−.073	−.067	−.070
16	−.081	−.072	−.065	−.068	−.060
17	−.110	−.095	−.095	−.087	−.082

TABLE IV

THRUST COEFFICIENT

$$C_T=\frac{(T-\Delta D)}{\rho n^2 D^4}$$

CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 *R*.

Nacelle position	$\frac{V}{nD}$								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°									
1	0.0833	0.0797	0.0739	0.0656	0.0550	0.0433	0.0310	0.0172	0.0000
2	.0819	.0780	.0724	.0650	.0555	.0437	.0299	.0145	−.0025
3	.0826	.0796	.0729	.0651	.0549	.0435	.0310	.0165	.0008
4	.0823	.0785	.0728	.0650	.0548	.0430	.0301	.0160	.0000
5	.0839	.0789	.0721	.0640	.0538	.0420	.0296	.0139	−.0050
6	.0834	.0794	.0736	.0651	.0544	.0425	.0296	.0150	−.0024
7	.0841	.0793	.0727	.0642	.0537	.0417	.0285	.0131	−.0039
8	.0838	.0797	.0735	.0655	.0545	.0423	.0289	.0132	−.0040
9	.0823	.0780	.0726	.0650	.0550	.0435	.0310	.0167	.0012
10	.0830	.0792	.0732	.0653	.0545	.0430	.0300	.0150	−.0010
11	.0832	.0785	.0725	.0646	.0547	.0435	.0303	.0150	−.0022
12	.0828	.0784	.0725	.0646	.0547	.0430	.0303	.0166	.0019
13	.0834	.0785	.0720	.0638	.0536	.0421	.0300	.0150	−.0030
14	.0853	.0806	.0746	.0665	.0563	.0447	.0310	.0160	.0002
15	.0818	.0774	.0714	.0635	.0534	.0422	.0301	.0160	−.0012
16	.0850	.0800	.0732	.0647	.0545	.0423	.0288	.0120	−.0077
17	.0838	.0791	.0730	.0649	.0545	.0430	.0291	.0140	−.0021
ANGLE OF ATTACK=0°									
1	0.0833	0.0800	0.0744	0.0664	0.0557	0.0438	0.0313	0.0173	0.0000
2	.0822	.0788	.0732	.0660	.0556	.0434	.0299	.0153	.0000
3	.0832	.0793	.0734	.0655	.0550	.0427	.0295	.0150	−.0030
4	.0827	.0785	.0726	.0648	.0549	.0431	.0301	.0162	.0019
5	.0838	.0790	.0725	.0640	.0537	.0419	.0287	.0129	−.0049
6	.0836	.0788	.0725	.0640	.0544	.0429	.0296	.0142	−.0031
7	.0854	.0800	.0730	.0640	.0535	.0410	.0277	.0117	−.0064
8	.0832	.0788	.0727	.0647	.0547	.0423	.0284	.0138	−.0029
9	.0810	.0770	.0713	.0642	.0550	.0437	.0305	.0160	.0005
10	.0839	.0793	.0735	.0655	.0553	.0437	.0302	.0162	.0015
11	.0835	.0790	.0728	.0649	.0550	.0440	.0317	.0170	.0008
12	.0838	.0792	.0730	.0651	.0545	.0430	.0308	.0152	−.0012
13	.0835	.0787	.0721	.0640	.0540	.0426	.0300	.0148	−.0018
14	.0863	.0815	.0750	.0668	.0566	.0450	.0319	.0163	.0000
15	.0822	.0778	.0718	.0639	.0535	.0420	.0297	.0151	−.0010
16	.0845	.0797	.0730	.0647	.0540	.0410	.0261	.0090	−.0100
17	.0842	.0797	.0736	.0653	.0550	.0430	.0292	.0150	−.0003
ANGLE OF ATTACK=5°									
1	0.0833	0.0792	0.0729	0.0644	0.0537	0.0423	0.0303	0.0165	0.0000
2	.0830	.0788	.0729	.0650	.0550	.0435	.0300	.0162	.0018
3	.0812	.0765	.0702	.0620	.0525	.0410	.0281	.0142	−.0002
4	.0830	.0786	.0727	.0647	.0547	.0430	.0300	.0158	.0011
5	.0814	.0765	.0700	.0618	.0519	.0406	.0271	.0109	−.0070
6	.0840	.0797	.0733	.0646	.0534	.0412	.0281	.0120	−.0064
7	.0848	.0796	.0726	.0636	.0528	.0404	.0270	.0111	−.0060
8	.0836	.0793	.0733	.0653	.0545	.0421	.0283	.0130	−.0031
9	.0825	.0780	.0718	.0640	.0543	.0433	.0315	.0170	.0013
10	.0833	.0788	.0725	.0643	.0542	.0428	.0300	.0160	.0013
11	.0830	.0788	.0730	.0652	.0556	.0441	.0315	.0167	−.0009
12	.0834	.0793	.0733	.0655	.0554	.0433	.0303	.0157	−.0002
13	.0821	.0778	.0720	.0645	.0550	.0439	.0309	.0159	−.0008
14	.0850	.0805	.0743	.0660	.0554	.0439	.0313	.0170	.0013
15	.0829	.0777	.0708	.0620	.0520	.0405	.0279	.0146	.0010
16	.0848	.0791	.0720	.0630	.0520	.0391	.0250	.0080	−.0107
17	.0845	.0798	.0736	.0655	.0560	.0441	.0309	.0160	.0005
ANGLE OF ATTACK=10°									
1	0.0829	0.0782	0.0715	0.0629	0.0526	0.0416	0.0298	0.0165	0.0000
2	.0806	.0760	.0696	.0614	.0516	.0402	.0280	.0143	.0002
3	.0785	.0738	.0673	.0596	.0502	.0398	.0281	.0145	−.0040
4	.0814	.0769	.0708	.0628	.0527	.0409	.0285	.0154	.0020
5	.0800	.0751	.0686	.0601	.0500	.0380	.0245	.0099	−.0058
6	.0813	.0762	.0696	.0610	.0505	.0385	.0257	.0118	−.0051
7	.0825	.0769	.0699	.0611	.0513	.0400	.0271	.0112	−.0057
8	.0821	.0771	.0702	.0619	.0513	.0399	.0266	.0114	−.0048
9	.0810	.0769	.0710	.0637	.0548	.0440	.0322	.0190	.0043
10	.0820	.0775	.0711	.0630	.0535	.0420	.0293	.0161	.0020
11	.0820	.0777	.0716	.0640	.0546	.0435	.0311	.0179	.0030
12	.0817	.0779	.0719	.0639	.0541	.0433	.0316	.0184	.0026
13	.0838	.0789	.0723	.0640	.0539	.0425	.0302	.0171	.0036
14	.0838	.0793	.0735	.0658	.0557	.0438	.0307	.0161	.0000
15	.0813	.0763	.0699	.0611	.0501	.0379	.0247	.0110	−.0040
16	.0822	.0770	.0700	.0611	.0505	.0380	.0240	.0090	−.0068
17	.0838	.0804	.0746	.0670	.0570	.0450	.0325	.0197	.0063

TABLE V

POWER COEFFICIENT

$$C_P = \frac{P}{\rho n^3 D^5}$$

CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 R.

Nacelle position	$\frac{V}{nD}$								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°									
1	0.0432	0.0428	0.0420	0.0402	0.0369	0.0326	0.0270	0.0188	0.0074
2	.0425	.0420	.0408	.0390	.0365	.0325	.0263	.0171	.0058
3	.0440	.0436	.0420	.0398	.0370	.0326	.0268	.0184	.0081
4	.0439	.0438	.0429	.0410	.0370	.0325	.0268	.0180	.0059
5	.0433	.0430	.0411	.0388	.0354	.0315	.0254	.0159	.0030
6	.0420	.0417	.0409	.0391	.0358	.0314	.0258	.0167	.0042
7	.0427	.0420	.0410	.0390	.0360	.0312	.0250	.0154	.0029
8	.0431	.0424	.0412	.0392	.0355	.0314	.0253	.0160	.0040
9	.0424	.0420	.0407	.0390	.0362	.0320	.0265	.0180	.0070
10	.0425	.0420	.0410	.0394	.0360	.0320	.0262	.0178	.0062
11	.0430	.0423	.0412	.0393	.0363	.0323	.0265	.0178	.0003
12	.0420	.0415	.0401	.0384	.0358	.0318	.0260	.0180	.0067
13	.0415	.0411	.0402	.0385	.0353	.0310	.0253	.0163	.0040
14	.0430	.0425	.0418	.0400	.0370	.0324	.0260	.0176	.0069
15	.0421	.0420	.0409	.0390	.0360	.0318	.0260	.0175	.0060
16	.0423	.0417	.0403	.0383	.0353	.0309	.0241	.0149	.0030
17	.0440	.0428	.0411	.0390	.0355	.0312	.0254	.0163	.0048
ANGLE OF ATTACK=0°									
1	0.0432	0.0430	0.0422	0.0403	0.0370	0.0328	0.0270	0.0183	0.0067
2	.0426	.0421	.0412	.0395	.0363	.0320	.0265	.0173	.0052
3	.0430	.0430	.0422	.0406	.0372	.0330	.0269	.0180	.0067
4	.0439	.0437	.0426	.0408	.0370	.0328	.0268	.0180	.0061
5	.0424	.0420	.0410	.0392	.0360	.0312	.0250	.0151	.0029
6	.0421	.0419	.0410	.0390	.0359	.0315	.0250	.0160	.0046
7	.0420	.0419	.0410	.0392	.0360	.0315	.0244	.0144	.0020
8	.0420	.0415	.0406	.0390	.0360	.0317	.0252	.0159	.0033
9	.0420	.0415	.0406	.0392	.0366	.0328	.0270	.0186	.0082
10	.0430	.0430	.0416	.0394	.0365	.0324	.0268	.0182	.0065
11	.0433	.0428	.0415	.0396	.0363	.0325	.0270	.0179	.0065
12	.0423	.0420	.0410	.0394	.0363	.0319	.0260	.0173	.0060
13	.0418	.0410	.0401	.0386	.0358	.0314	.0252	.0161	.0043
14	.0428	.0429	.0422	.0410	.0372	.0330	.0270	.0180	.0060
15	.0418	.0415	.0408	.0394	.0360	.0320	.0260	.0170	.0060
16	.0420	.0416	.0405	.0387	.0350	.0300	.0231	.0131	.0007
17	.0420	.0418	.0408	.0391	.0362	.0319	.0259	.0172	.0061
ANGLE OF ATTACK=5°									
1	0.0432	0.0428	0.0422	0.0403	0.0370	0.0327	0.0267	0.0181	0.0061
2	.0435	.0431	.0421	.0403	.0372	.0326	.0265	.0180	.0060
3	.0435	.0427	.0413	.0395	.0365	.0324	.0261	.0178	.0075
4	.0430	.0425	.0415	.0400	.0370	.0325	.0268	.0180	.0062
5	.0420	.0417	.0408	.0390	.0354	.0308	.0243	.0144	.0019
6	.0424	.0419	.0408	.0389	.0360	.0313	.0250	.0155	.0040
7	.0425	.0420	.0408	.0383	.0351	.0304	.0241	.0143	.0020
8	.0421	.0410	.0410	.0391	.0360	.0315	.0250	.0155	.0038
9	.0428	.0423	.0411	.0394	.0368	.0330	.0277	.0193	.0080
10	.0426	.0421	.0411	.0394	.0363	.0325	.0270	.0181	.0070
11	.0438	.0435	.0420	.0395	.0363	.0327	.0275	.0192	.0073
12	.0431	.0425	.0411	.0391	.0364	.0321	.0265	.0178	.0063
13	.0418	.0413	.0407	.0390	.0359	.0317	.0260	.0173	.0060
14	.0430	.0430	.0422	.0407	.0370	.0328	.0270	.0182	.0070
15	.0430	.0426	.0413	.0394	.0361	.0320	.0261	.0173	.0059
16	.0424	.0413	.0400	.0378	.0346	.0298	.0230	.0122	----
17	.0428	.0420	.0409	.0390	.0367	.0330	.0270	.0186	.0080
ANGLE OF ATTACK=10°									
1	0.0431	0.0428	0.0421	0.0403	0.0371	0.0327	0.0268	0.0187	0.0064
2	.0430	.0428	.0419	.0401	.0370	.0330	.0271	.0187	.0070
3	.0427	.0425	.0418	.0400	.0370	.0326	.0270	.0185	.0078
4	.0429	.0428	.0420	.0405	.0373	.0329	.0270	.0180	.0061
5	.0420	.0420	.0408	.0387	.0354	.0310	.0245	.0147	.0020
6	.0421	.0418	.0409	.0390	.0360	.0318	.0252	.0160	.0041
7	.0419	.0414	.0405	.0387	.0353	.0307	.0240	.0142	.0024
8	.0422	.0420	.0411	.0394	.0361	.0318	.0250	.0156	.0034
9	.0426	.0424	.0417	.0401	.0373	.0336	.0284	.0202	.0090
10	.0425	.0425	.0418	.0400	.0371	.0330	.0273	.0190	.0081
11	.0434	.0434	.0423	.0404	.0372	.0334	.0280	.0201	.0090
12	.0422	.0421	.0416	.0400	.0369	.0327	.0271	.0188	.0072
13	.0418	.0418	.0410	.0398	.0363	.0322	.0269	.0185	.0071
14	.0429	.0430	.0424	.0410	.0377	.0332	.0274	.0190	.0084
15	.0420	.0421	.0418	.0400	.0366	.0321	.0265	.0180	.0062
16	.0423	.0417	.0403	.0382	.0347	.0297	.0220	.0120	----
17	.0430	.0430	.0420	.0405	.0376	.0334	.0280	.0204	.0104

TABLE VI

PROPULSIVE EFFICIENCY

$$\eta = \frac{(T-\Delta D)V}{P}$$

CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 *R*.

Nacelle position	$\frac{V}{nD}$								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°									
1	0.193	0.373	0.528	0.652	0.745	0.798	0.804	0.732	0.000
2	.193	.372	.532	.667	.760	.807	.796	.679	-----
3	.188	.361	.520	.655	.742	.801	.810	.718	.089
4	.188	.358	.509	.634	.741	.794	.787	.711	.000
5	.194	.367	.526	.660	.760	.801	.816	.700	-----
6	.198	.380	.540	.667	.760	.813	.807	.718	-----
7	.197	.378	.532	.658	.746	.802	.798	.681	-----
8	.194	.376	.535	.669	.768	.808	.800	.660	-----
9	.194	.372	.535	.667	.760	.816	.819	.742	.154
10	.195	.377	.536	.663	.757	.806	.802	.674	-----
11	.193	.371	.528	.658	.754	.808	.801	.675	-----
12	.197	.378	.542	.673	.764	.812	.816	.738	.255
13	.201	.382	.537	.663	.759	.815	.830	.736	-----
14	.198	.378	.535	.665	.761	.828	.835	.727	.026
15	.194	.368	.524	.651	.742	.797	.811	.732	-----
16	.201	.384	.545	.676	.772	.820	.837	.645	-----
17	.191	.370	.533	.665	.768	.827	.802	.687	-----
ANGLE OF ATTACK=0°									
1	0.193	0.372	0.528	0.659	0.753	0.801	0.811	0.756	0.000
2	.193	.374	.533	.669	.766	.812	.792	.708	.000
3	.194	.369	.522	.645	.740	.777	.768	.667	-----
4	.188	.359	.511	.636	.742	.789	.786	.720	.280
5	.198	.376	.530	.653	.746	.806	.804	.684	-----
6	.199	.376	.530	.656	.758	.818	.813	.710	-----
7	.203	.382	.534	.653	.743	.781	.795	.650	-----
8	.198	.380	.537	.664	.761	.800	.789	.695	-----
9	.193	.371	.527	.655	.751	.799	.791	.689	.055
10	.195	.369	.530	.665	.758	.810	.789	.712	.208
11	.193	.369	.526	.655	.758	.812	.822	.760	.111
12	.198	.377	.534	.661	.751	.809	.829	.703	-----
13	.202	.384	.540	.663	.754	.814	.831	.736	-----
14	.202	.380	.533	.652	.761	.819	.827	.724	.000
15	.197	.375	.528	.649	.743	.788	.800	.711	-----
16	.201	.383	.541	.669	.771	.820	.791	.550	-----
17	.200	.381	.542	.668	.760	.809	.790	.698	-----
ANGLE OF ATTACK=5°									
1	0.193	0.370	0.518	0.639	0.726	0.776	0.794	0.728	0.000
2	.191	.365	.520	.645	.739	.801	.793	.720	.270
3	.187	.358	.510	.628	.719	.759	.754	.638	-----
4	.193	.370	.525	.647	.739	.794	.784	.703	.160
5	.194	.367	.515	.634	.733	.791	.781	.606	-----
6	.198	.380	.539	.664	.742	.790	.788	.620	-----
7	.200	.379	.534	.664	.752	.798	.784	.621	-----
8	.198	.378	.536	.668	.757	.802	.793	.672	-----
9	.193	.369	.524	.650	.738	.787	.796	.705	.146
10	.196	.374	.529	.653	.747	.790	.778	.708	.167
11	.190	.362	.521	.660	.766	.809	.802	.696	-----
12	.193	.373	.534	.670	.760	.809	.801	.706	-----
13	.197	.377	.531	.662	.766	.831	.832	.735	-----
14	.198	.374	.528	.649	.749	.803	.812	.747	.167
15	.193	.365	.514	.629	.721	.759	.749	.676	.152
16	.200	.383	.540	.666	.751	.787	.761	.525	-----
17	.198	.380	.540	.672	.762	.802	.801	.688	.056
ANGLE OF ATTACK=10°									
1	0.193	0.365	0.510	0.624	0.708	0.763	0.778	0.706	0.000
2	.188	.355	.498	.612	.700	.731	.723	.612	.070
3	.184	.347	.483	.596	.679	.733	.729	.627	-----
4	.190	.359	.506	.620	.706	.746	.739	.684	.295
5	.191	.358	.505	.621	.706	.736	.700	.539	-----
6	.193	.364	.510	.626	.702	.727	.714	.591	-----
7	.197	.372	.518	.632	.727	.782	.790	.632	-----
8	.194	.367	.512	.629	.710	.748	.745	.585	-----
9	.190	.363	.511	.635	.735	.786	.794	.752	.430
10	.193	.365	.510	.630	.721	.764	.751	.678	.222
11	.189	.358	.508	.634	.734	.782	.783	.712	.300
12	.194	.370	.518	.639	.733	.794	.819	.784	.325
13	.200	.378	.529	.643	.742	.792	.787	.740	.456
14	.195	.369	.520	.642	.739	.791	.784	.678	.000
15	.194	.363	.502	.611	.684	.709	.653	.489	-----
16	.194	.370	.521	.640	.728	.768	.764	.600	-----
17	.195	.374	.533	.662	.758	.808	.812	.773	.545

TABLE VII

LIFT COEFFICIENT WITH PROPELLER OPERATING

$$C_{L_P}=\frac{L_P}{qS}$$

CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 *R*.

Nacelle position	$\frac{V}{nD}$						Nacelle position	$\frac{V}{nD}$					
	0.4	0.5	0.6	0.7	0.8	0.9		0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°													
1	−0.030	−0.029	−0.027	−0.024	−0.024	−0.025	10	0.000	0.049	0.058	0.052	0.045	0.040
2	−.050	−.038	−.019	.005	.008	−.012	11	−.097	−.007	.001	.004	.015	.030
3	.020	.018	.010	.000	−.010	−.020	12	−.029	−.006	.011	.021	.028	.033
4	−.008	−.005	−.007	−.011	−.015	−.015	13	−.062	−.027	.000	.019	.022	.010
5	.045	.042	.027	.012	.001	−.007	14	−.008	.013	.018	.020	.022	.023
6	.059	.022	.030	.019	.006	.006	15	−.023	−.017	−.013	−.012	−.013	−.010
7	.029	.030	.026	.018	.010	.001	16	.062	.059	.047	.030	.013	.008
8	.031	.030	.025	.015	.010	.010	17	−.076	−.040	−.013	−.001	.004	.010
9	−.048	.000	.020	.028	.031	.033							
ANGLE OF ATTACK=0°													
1	0.335	0.315	0.296	0.283	0.272	0.262	10	0.344	0.349	0.350	0.351	0.351	0.351
2	.320	.300	.290	.289	.288	.288	11	.220	.278	.303	.314	.315	.310
3	.330	.315	.301	.289	.273	.254	12	.308	.316	.321	.327	.329	.320
4	.334	.306	.285	.272	.263	.256	13	.265	.286	.303	.319	.320	.319
5	.405	.359	.325	.321	.312	.290	14	.309	.313	.318	.320	.319	.318
6	.350	.335	.323	.316	.310	.308	15	.300	.294	.289	.281	.276	.270
7	.383	.338	.317	.312	.310	.300	16	.401	.366	.340	.320	.310	.303
8	.388	.352	.327	.310	.308	.307	17	.253	.279	.290	.295	.299	.301
9	.296	.320	.330	.330	.331	.331							
ANGLE OF ATTACK=5°													
1	0.641	0.613	0.595	0.583	0.574	0.569	10	0.681	0.670	0.662	0.657	0.651	0.649
2	.626	.613	.604	.601	.600	.600	11	.591	.608	.614	.619	.619	.614
3	.660	.630	.607	.589	.575	.566	12	.640	.640	.640	.640	.640	.640
4	.620	.600	.589	.582	.583	.586	13	.615	.620	.622	.625	.626	.620
5	.702	.663	.618	.607	.614	.611	14	.639	.630	.625	.623	.622	.020
6	.708	.659	.630	.612	.600	.590	15	.620	.604	.590	.580	.572	.565
7	.672	.641	.622	.612	.610	.613	16	.677	.652	.636	.623	.615	.610
8	.670	.641	.620	.610	.605	.608	17	.597	.600	.601	.603	.605	.609
9	.647	.640	.639	.638	.639	.640							
ANGLE OF ATTACK=10°													
1	0.953	0.933	0.918	0.906	0.899	0.894	10	1.018	0.992	0.976	0.965	0.959	0.957
2	.972	.943	.924	.911	.902	.895	11	.916	.912	.915	.920	.922	.923
3	1.013	.952	.915	.890	.874	.863	12	.949	.945	.941	.939	.937	.934
4	.950	.917	.900	.893	.885	.879	13	.923	.921	.920	.918	.917	.915
5	1.002	.959	.928	.914	.907	.893	14	.944	.939	.933	.930	.930	.930
6	1.010	.952	.920	.904	.902	.906	15	.957	.920	.893	.876	.867	.861
7	1.003	.960	.937	.921	.910	.900	16	.995	.958	.931	.920	.912	.910
8	1.008	.947	.919	.906	.905	.906	17	.902	.903	.905	.906	.907	.909
9	.954	.951	.949	.947	.945	.943							

TABLE VIII

MOMENT COEFFICIENT WITH PROPELLER OPERATING

$$C_{m_P}=\frac{M_P}{qSc}$$

CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 *R*.

Nacelle position	$\frac{V}{nD}$						Nacelle position	$\frac{V}{nD}$					
	0.4	0.5	0.6	0.7	0.8	0.9		0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°													
1	−0.099	−0.094	−0.090	−0.088	−0.087	−0.088	10	−0.038	−0.060	−0.074	−0.082	−0.088	−0.091
2	−.091	−.091	−.091	−.090	−.090	−.090	11	.044	−.009	−.047	−.073	−.089	−.100
3	−.225	−.169	−.139	−.120	−.108	−.101	12	.064	.002	−.038	−.063	−.078	−.087
4	−.207	−.156	−.127	−.109	−.096	−.088	13	.094	.021	−.030	−.065	−.090	−.109
5	−.299	−.194	−.143	−.116	−.099	−.088	14	.112	.039	−.018	−.060	−.086	−.099
6	−.296	−.192	−.142	−.113	−.092	−.078	15	−.090	−.088	−.086	−.085	−.085	−.086
7	−.382	−.221	−.152	−.115	−.090	−.072	16	−.370	−.220	−.154	−.116	−.092	−.075
8	−.380	−.215	−.154	−.116	−.089	−.070	17	.107	.025	−.031	−.067	−.090	−.108
9	.003	−.035	−.060	−.074	−.082	−.087							
ANGLE OF ATTACK=0°													
1	−0.090	−0.087	−0.034	−0.082	−0.081	−0.081	10	−0.017	−0.042	−0.063	−0.075	−0.080	−0.082
2	−.090	−.086	−.085	−.083	−.083	−.033	11	.038	.003	−.034	−.060	−.077	−.087
3	−.230	−.168	−.138	−.119	−.103	−.099	12	.064	.003	−.031	−.057	−.074	−.085
4	−.207	−.147	−.119	−.101	−.090	−.085	13	.133	.041	−.019	−.057	−.082	−.099
5	−.270	−.175	−.129	−.103	−.085	−.075	14	.130	.049	−.010	−.049	−.077	−.098
6	−.293	−.181	−.133	−.107	−.090	−.079	15	−.087	−.084	−.081	−.080	−.079	−.079
7	−.372	−.205	−.148	−.113	−.089	−.072	16	−.385	−.199	−.144	−.110	−.084	−.063
8	−.355	−.201	−.147	−.112	−.086	−.067	17	.124	.037	−.022	−.060	−.085	−.101
9	−.010	−.039	−.059	−.071	−.078	−.082							
ANGLE OF ATTACK=5°													
1	−0.093	−0.089	−0.086	−0.084	−0.083	−0.082	10	−0.015	−0.043	−0.061	−0.073	−0.079	−0.083
2	−.090	−.090	−.089	−.089	−.089	−.089	11	.060	.004	−.038	−.066	−.084	−.093
3	−.225	−.163	−.130	−.110	−.098	−.091	12	.072	.009	−.035	−.062	−.080	−.090
4	−.173	−.140	−.117	−.100	−.087	−.079	13	.138	.044	−.016	−.052	−.078	−.095
5	−.276	−.183	−.133	−.107	−.091	−.082	14	.143	.047	−.013	−.053	−.079	−.098
6	−.268	−.181	−.135	−.107	−.089	−.077	15	−.087	−.084	−.082	−.080	−.080	−.079
7	−.337	−.205	−.150	−.114	−.087	−.064	16	−.330	−.198	−.139	−.106	−.082	−.065
8	−.325	−.221	−.151	−.113	−.087	−.067	17	.150	.044	−.018	−.057	−.080	−.097
9	.015	−.029	−.052	−.085	−.072	−.076							
ANGLE OF ATTACK=10°													
1	−0.090	−0.090	−0.087	−0.082	−0.076	−0.069	10	−0.018	−0.043	−0.058	−0.068	−0.074	−0.076
2	−.095	−.093	−.091	−.089	−.087	−.085	11	.066	.007	−.032	−.056	−.073	−.082
3	−.208	−.159	−.128	−.107	−.094	−.085	12	.056	.004	−.034	−.059	−.075	−.084
4	−.189	−.142	−.117	−.103	−.093	−.087	13	.168	.053	−.008	−.045	−.071	−.090
5	−.256	−.178	−.133	−.105	−.086	−.072	14	.142	.049	−.010	−.050	−.078	−.097
6	−.267	−.180	−.139	−.111	−.090	−.075	15	−.095	−.090	−.086	−.082	−.079	−.075
7	−.315	−.208	−.146	−.109	−.082	−.062	16	−.315	−.200	−.140	−.100	−.074	−.055
8	−.347	−.224	−.157	−.116	−.086	−.064	17	.161	.037	−.016	−.049	−.069	−.080
9	.006	−.030	−.053	−.067	−.073	−.076							

TABLE IX

LIFT AND DRAG COEFFICIENTS WITHOUT PROPELLER

THICK WING

LIFT COEFFICIENT WITHOUT PROPELLER. $C_L=\frac{\text{lift}}{qS}$

	50 m.p.h. R.N.=2,150,000				75 m.p.h. R.N.=3,220,000				100 m.p.h. R.N.=4,300,000				
Angle of attack	−5°	0°	5°	10°	−5°	0°	5°	10°	−5°	0°	5°	10°	12°
NACELLE NO. 1, VARIABLE-ANGLE RING SET 5°													
Nacelle position													
2	0.150	0.392	0.631	0.873	0.144	0.386	0.626	0.868	0.135	0.377	0.618	0.860	0.954
7	.188	.424	.659	.892	.181	.418	.655	.890	.171	.409	.650	.888	.982
13	.198	.438	.677	.913	.188	.431	.671	.910	.175	.420	.663	.907	1.005
ELECTRIC MOTOR ONLY FAIRED INTO WING													
1	0.192	0.429	0.661	0.893	0.182	0.421	0.656	0.893	0.169	0.410	0.649	0.893	0.979
2	.185	.420	.653	.886	.172	.411	.648	.886	.154	.398	.641	.886	.983
WING ALONE													
	0.179	0.417	0.652	0.889	0.175	0.414	0.650	0.887	0.169	0.409	0.646	0.885	0.960

DRAG COEFFICIENT WITHOUT PROPELLER. $C_D=\frac{\text{drag}}{qS}$

	50 m.p.h. R.N.=2,150,000				75 m.p.h. R.N.=3,220,000				100 m.p.h. R.N.=4,300,000				
Angle of attack	−5°	0°	5°	10°	−5°	0°	5°	10°	−5°	0°	5°	10°	12°
NACELLE NO. 1. VARIABLE-ANGLE RING SET 5°													
Nacelle position													
2	0.0255	0.0460	0.0880	0.1490	0.0250	0.0455	0.0875	0.1490	0.0240	0.0445	0.0870	0.1490	0.1770
7	.0320	.0530	.0975	.1580	.0315	.0525	.0970	.1580	.0310	.0520	.0965	.1575	.1880
13	.0300	.0530	.0985	.1595	.0285	.0520	.0980	.1595	.0270	.0500	.0965	.1595	.1890
ELECTRIC MOTOR ONLY FAIRED INTO WING													
1	0.0200	0.0430	0.0880	0.1485	0.0190	0.0420	0.0875	0.1485	0.0180	0.0410	0.0865	0.1485	0.1740
2	.0200	.0425	.0880	.1480	.0190	.0415	.0870	.1480	.0180	.0405	.0860	.1480	.1770
WING ALONE													
	0.0180	0.0425	0.0830	0.1440	0.0175	0.0415	0.0825	0.1440	0.0165	0.0405	0.0825	0.1440	0.1740

TABLE X

MOMENT COEFFICIENT WITHOUT PROPELLER. $C_m=\frac{\text{moment}}{qSc}$

THICK WING

Nacelle position	Angle of attack				
	−5°	0°	5°	10°	12°
NACELLE 1, VARIABLE-ANGLE RING SET 5°					
2	−0.071	−0.068	−0.067	−0.069	−0.071
7	−.072	−.066	−.069	−.075	−.078
13	−.073	−.076	−.077	−.082	−.080
ELECTRIC MOTOR ONLY FAIRED INTO WING					
1	−0.085	−0.080	−0.078	−0.081	−0.077
2	−.081	−.080	−.077	−.083	−.085

TABLE XI

THRUST COEFFICIENT

$$C_T = \frac{(T-\Delta D)}{\rho n^2 D^4}$$

THICK WING

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 R

Nacelle position	$\frac{V}{nD}$ 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°									
Nacelle 1, variable-angle ring set 5°									
2	0.0824	0.0783	0.0723	0.0642	0.0537	0.0423	0.0301	0.0173	0.0024
7	.0835	.0787	.0724	.0640	.0538	.0413	.0283	.0129	−.0040
13	.0845	.0805	.0743	.0662	.0551	.0429	.0300	.0152	−.0010
Electric motor only faired into wing									
1	0.0854	0.0817	0.0759	0.0677	0.0568	0.0445	0.0315	0.0173	0.0021
2	.0867	.0813	.0742	.0657	.0559	.0442	.0306	.0154	−.0015
ANGLE OF ATTACK=0°									
Nacelle 1, variable-angle ring set 5°									
2	0.0830	0.0790	0.0729	0.0648	0.0544	0.0430	0.0308	0.0177	0.0027
7	.0843	.0789	.0717	.0629	.0525	.0409	.0271	.0126	−.0029
13	.0850	.0810	.0749	.0670	.0560	.0445	.0326	.0178	.0002
Electric motor only faired into wing									
1	0.0853	0.0807	0.0742	0.0658	0.0556	0.0440	0.0315	0.0170	0.0010
2	.0882	.0833	.0764	.0676	.0566	.0443	.0305	.0153	−.0018
ANGLE OF ATTACK=5°									
Nacelle 1, variable-angle ring set 5°									
2	0.0830	0.0788	0.0727	0.0644	0.0533	0.0416	0.0296	0.0168	0.0023
7	.0830	.0773	.0700	.0610	.0503	.0388	.0260	.0100	−.0076
13	.0850	.0822	.0768	.0685	.0571	.0451	.0327	.0180	.0018
Electric motor only faired into wing									
1	0.0853	0.0808	0.0741	0.0658	0.0553	0.0437	0.0310	0.0165	0.0006
2	.0867	.0807	.0740	.0656	.0554	.0430	.0302	.0158	.0012

TABLE XII

POWER COEFFICIENT

$$C_P = \frac{P}{\rho n^3 D^5}$$

THICK WING

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 R

Nacelle position	$\frac{V}{nD}$								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°									
	Nacelle 1, variable-angle ring set 5°								
2	0.0419	0.0415	0.0406	0.0388	0.0363	0.0323	0.0270	0.0192	0.0080
7	.0422	.0420	.0410	.0391	.0355	.0310	.0248	.0159	.0040
13	.0415	.0411	.0402	.0388	.0360	.0320	.0263	.0180	.0078
	Electric motor only faired into wing								
1	0.0430	0.0429	0.0420	0.0400	0.0369	0.0324	0.0267	0.0187	0.0079
2	.0425	.0417	.0406	.0390	.0364	.0323	.0263	.0177	.0061
ANGLE OF ATTACK=0°									
	Nacelle 1, variable-angle ring set 5°								
2	0.0421	0.0418	0.0410	0.0396	0.0370	0.0329	0.0273	0.0193	0.0086
7	.0420	.0418	.0410	.0393	.0356	.0310	.0244	.0150	.0035
13	.0420	.0420	.0410	.0395	.0365	.0326	.0272	.0190	.0080
	Electric motor only faired into wing								
1	0.0424	0.0420	0.0410	0.0392	0.0367	0.0328	0.0270	0.0186	0.0067
2	.0425	.0419	.0407	.0393	.0367	.0324	.0263	.0179	.0066
ANGLE OF ATTACK=5°									
	Nacelle 1, variable-angle ring set 5°								
2	0.0427	0.0424	0.0414	0.0401	0.0372	0.0328	0.0273	0.0193	0.0083
7	.0411	.0410	.0400	.0383	.0350	.0305	.0240	.0142	.0024
13	.0419	.0420	.0415	.0400	.0367	.0322	.0269	.0185	.0080
	Electric motor only faired into wing								
1	0.0424	0.0423	0.0415	0.0398	0.0370	0.0329	0.0274	0.0197	0.0088
2	.0417	.0412	.0404	.0391	.0366	.0325	.0263	.0178	.0067

TABLE XIII

PROPULSIVE EFFICIENCY

$$\eta=\frac{(T-\Delta D)V}{P}$$

THICK WING

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 R

Nacelle position	$\frac{V}{nD}$ 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°									
	Nacelle 1, variable-angle ring set 5°								
2	0.197	0.378	0.535	0.663	0.740	0.786	0.781	0.721	0.270
7	.198	.375	.530	.655	.758	.800	.799	.649	----------
13	.204	.392	.554	.682	.766	.804	.799	.675	----------
	Electric motor only faired into wing								
1	0.199	0.381	0.542	0.677	0.770	0.824	0.826	0.740	0.240
2	.204	.389	.548	.675	.763	.821	.815	.696	----------
ANGLE OF ATTACK=0°									
	Nacelle 1, variable-angle ring set 5°								
2	0.197	0.378	0.533	0.655	0.735	0.784	0.790	0.734	0.283
7	.201	.377	.504	.640	.738	.792	.778	.672	----------
13	.203	.386	.548	.678	.767	.819	.840	.750	.023
	Electric motor only faired into wing								
1	0.201	0.384	0.543	0.671	0.757	0.805	0.817	0.731	0.135
2	.207	.397	.563	.689	.771	.820	.812	.684	----------
ANGLE OF ATTACK=5°									
	Nacelle 1, variable-angle ring set 5°								
2	0.194	0.372	0.526	0.643	0.716	0.761	0.758	0.697	0.219
7	.202	.377	.525	.637	.718	.764	.758	.563	----------
13	.203	.391	.555	.635	.778	.841	.851	.779	.202
	Electric motor only faired into wing								
1	0.201	0.382	0.536	0.662	0.747	0.796	0.792	0.670	0.062
2	.208	.392	.549	.672	.757	.793	.804	.711	.163

TABLE XIV

LIFT COEFFICIENT WITH PROPELLER OPERATING

$$C_{L_P}=\frac{L_P}{qS}$$

THICK WING

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 *R*

Nacelle position	$\frac{V}{nD}$					
	0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°						
	Nacelle 1, variable-angle ring set 5°					
2	0.152	0.143	0.138	0.133	0.128	0.125
7	.168	.191	.184	.173	.156	.141
13	.131	.145	.152	.154	.156	.165
	Electric motor only faired into wing					
1	0.186	0.180	0.172	0.164	0.159	0.152
2	.177	.177	.173	.165	.156	.146
ANGLE OF ATTACK=0°						
	Nacelle 1, variable-angle ring set 5°					
2	0.405	0.396	0.387	0.383	0.379	0.376
7	.447	.441	.419	.403	.393	.393
13	.396	.405	.412	.416	.421	.423
	Electric motor only faired into wing					
1	0.423	0.423	0.421	0.417	0.411	0.403
2	.417	.417	.416	.412	.407	.400
ANGLE OF ATTACK=5°						
	Nacelle 1, variable-angle ring set 5°					
2	0.655	0.644	0.635	0.628	0.623	0.019
7	.699	.668	.653	.645	.643	.644
13	.653	.651	.657	.662	.665	.666
	Electric motor only faired into wing					
1	0.686	0.678	0.668	0.660	0.651	0.642
2	.663	.662	.660	.655	.648	.642

TABLE XV

MOMENT COEFFICIENT WITH PROPELLER OPERATING

$$C_{m_P}=\frac{M_P}{qSc}$$

THICK WING

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 *R*

Nacelle position	$\frac{V}{nD}$					
	0.4	0.5	0.6	0.7	0.8	0.9
ANGLE OF ATTACK=−5°						
	Nacelle 1, variable-angle ring set 5°					
2	−0.077	−0.076	−0.075	−0.075	−0.074	−0.073
7	−.204	−.139	−.103	−.088	−.075	−.007
13	.016	−.024	−.047	−.062	−.071	−.077
	Electric motor only faired into wing					
1	−0.116	−0.098	−0.091	−0.087	−0.083	−0.081
2	−.099	−.093	−.089	−.085	−.082	−.080
ANGLE OF ATTACK=0°						
	Nacelle 1, variable-angle ring set 5°					
2	−0.078	−0.073	−0.069	−0.066	−0.065	−0.065
7	−.205	−.134	−.102	−.083	−.071	−.065
13	.014	−.019	−.041	−.056	−.066	−.073
	Electric motor only faired into wing					
1	−0.100	−0.088	−0.083	−0.079	−0.076	−0.074
2	−.085	−.082	−.080	−.078	−.076	−.074
ANGLE OF ATTACK=5°						
	Nacelle 1, variable-angle ring set 5°					
2	−0.078	−0.075	−0.072	−0.068	−0.005	−0.003
7	−.197	−.133	−.101	−.084	−.074	−.009
13	.023	−.020	−.044	−.057	−.066	−.072
	Electric motor only faired into wing					
1	−0.097	−0.090	−0.086	−0.082	−0.079	−0.079
2	−.094	−.088	−.084	−.080	−.076	−.073

TABLE XVI

DRAG, MAXIMUM PROPULSIVE EFFICIENCY, AND NET EFFICIENCY

NACELLES TESTED ALONE

Nacelle	Cowling	Drag at 100 m.p.h. propeller removed	Propeller 4412, 4 feet. Set 17° at 0.75 R	
			Maximum propulsive efficiency	Net efficiency at $\frac{V}{nD}=0.65$
		Pounds		
1	Exposed cylinders	25.2	0.815	0.508
	Variable-angle ring set 0°	20.5	.806	.555
	Variable-angle ring set 5°	18.7	.811	.586
	Variable-angle ring set 10°	19.8	.817	.581
2	Exposed cylinders	25.6	.790	.471
	Variable-angle ring set 0°	20.3	.814	.555
	Variable-angle ring set 5°	20.3	.815	.568
	Variable-angle ring set 10°	34.1	.952	.525
Model engine on electric motor.	Exposed cylinders	29.0	.840	.462
	Variable-angle ring set 0°	21.4	.812	.542
	Variable-angle ring set 5°	27.2	.898	.555
	Variable-angle ring set 10°	51.7	.920	.303
Electric motor only		5.7	.822	.745

TABLE XVII

RELATIVE MERITS OF VARIOUS NACELLE LOCATIONS

CLARK Y WING. NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 R

Nacelle position	High and cruising speed condition $\frac{V}{nD}=0.65$ $\alpha=0°$			Climbing condition $\frac{V}{nD}=0.42$ $\alpha=5°$		
	Corrected propulsive efficiency, η	Nacelle drag efficiency factor, N.D.F.	Net efficiency, $\eta-$N.D.F.	Corrected propulsive efficiency, η	Nacelle drag efficiency factor, N.D.F.	Net efficiency, $\eta-$N.D.F.
1	0.812	0.177	0.635	0.675	0.043	0.632
2	.807	.179	.628	.674	.044	.630
3	.790	.254	.536	.673	.063	.610
4	.796	.189	.607	.680	.048	.632
5	.824	.248	.576	.684	.060	.624
6	.839	.222	.617	.708	.057	.651
7	.803	.264	.539	.702	.072	.630
8	.804	.254	.550	.701	.062	.639
9	.796	.160	.636	.670	.041	.629
10	.796	.188	.608	.675	.050	.625
11	.814	.168	.646	.677	.041	.636
12	.823	.203	.620	.689	.050	.639
13	.815	.204	.611	.678	.052	.626
14	.826	.196	.630	.672	.053	.619
15	.812	.204	.608	.668	.047	.621
16	.835	.288	.547	.704	.075	.629
17	.784	.211	.573	.687	.052	.635

TABLE XVIII

RELATIVE MERITS OF VARIOUS NACELLE LOCATIONS

THICK WING

PROPELLER NO. 4412, 4 FEET. SET 17° AT 0.75 R

Nacelle position	High and cruising speed condition $\frac{V}{nD}=0.65$ $\alpha=0°$			Climbing condition $\frac{V}{nD}=0.42$ $\alpha=5°$		
	Corrected propulsive efficiency, η	Nacelle drag efficiency factor, N.D.F.	Net efficiency, $\eta-$N.D.F.	Corrected propulsive efficiency, η	Nacelle drag efficiency factor, N.D.F.	Net efficiency, $\eta-$N.D.F.
NACELLE 1 WITH VARIABLE-ANGLE RING SET 5°						
2	0.807	0.161	0.646	0.678	0.039	0.639
7	.795	.265	.530	.681	.060	.621
13	.823	.177	.646	.685	.049	.636
ELECTRIC MOTOR ONLY FAIRED INTO WING						
1	0.841	0.009	0.832	0.701	0.016	0.685
2	.867	.028	.839	.702	.021	.631

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